

A History of Manned Lunar Spacecraft

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CHARIOTS FOR APOLLO



... I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.

25 May 1961



... July 1969 A.D. We came in peace for all mankind.

Frontispiece:

Astronaut Edwin Aldrin walks on the surface of the moon near a leg of the lunar module after the 20 July 1969 Apollo 11 landing. He was photographed by fellow crewman Neil Armstrong.

CHARIOTS FOR APOLLO



A History of Manned Lunar Spacecraft

by

COURTNEY G. BROOKS

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The NASA History Series



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Contents

	Page
FOREWORD	xi
PREFACE	xiii
1. CONCEPT TO CHALLENGE	1
2. PROJECT PLANNING AND CONTRACTING	33
3. CONTENDING MODES	61
4. MATCHING MODULES AND MISSIONS	87
5. COMMAND MODULE AND PROGRAM CHANGES	117
6. LUNAR MODULE	143
7. SEARCHING FOR ORDER	167
8. MOVING TOWARD OPERATIONS	189
9. TRAGEDY AND RECOVERY	213
10. RACE WITH THE DECADE	237
11. TASTES OF TRIUMPH	255
12. THE TRAILBLAZERS	285
13. TO LAND ON THE MOON	313
14. TRIP TO TRANQUILITY	337
EPILOGUE	361

CHARIOTS FOR APOLLO

	Page
APPENDIX A. MANNED SPACECRAFT CENTER SITE SELECTION PRO- CEDURE	369
APPENDIX B. ASTRONAUT ASSIGNMENTS	373
APPENDIX C. APOLLO FLIGHT PROGRAM	381
APPENDIX D. <i>Apollo 11</i> EXPERIMENTS	394
APPENDIX E. <i>Apollo 11</i> LUNAR SAMPLES	396
APPENDIX F. MAJOR SPACECRAFT COMPONENT MANUFACTURERS ..	399
APPENDIX G. APOLLO PROGRAM RESPONSIBILITIES OF THE MANNED SPACE CENTERS	401
APPENDIX H. FUNDING—AS OF 30 JUNE 1969	409
SOURCE NOTES	415
BIBLIOGRAPHICAL NOTE	485
INDEX	503

Illustrations

	Page
"We came in peace"	ii-iii
Lunar mission concepts, 1959	2
Administrator Glennan visits Langley Research Center	3
Army Ballistic Missile Agency concept of lunar landing vehicle	5
Lenticular vehicle operation	10
Launch vehicles leading to Saturn C-1 and proposed C-2	12
Robert Gilruth and aides discuss contractor selection for Apollo studies	16
Sketch of command module seating	18
Spacecraft models proposed by industry	28
Crew positions sketched by STG engineers in 1960	36
Spacecraft modules, mid-1961	36
Guidance and control system mockup and MIT Director Draper	40
Inertial measuring unit and technical design director Hoag, MIT	40
Static-firing facility, Redstone Arsenal	54
Mississippi Test Facility	54
Michoud Assembly Facility	54
Vehicle Assembly Building, Kennedy Space Center	55
Groundbreaking for MSC Operations and Checkout Building at the Cape	55
Manned Spacecraft Center	55
Launch of SA-1	56
Comparative sizes of Atlas, Titan II, Saturn C-5, and Nova	59
Three techniques for lunar landing	63
Two ways to land on the moon by direct ascent	63
Earth-orbit rendezvous	63
Lunar-surface rendezvous	64
Early lunar lander concepts	68, 74
Spacecraft configuration changes, May 1960-July 1962	86

LIST OF ILLUSTRATIONS

	Page
Webb and aides announce lunar-orbit rendezvous decision	86
Model showing docking technique	86
North American officials study moon model	88
North American Aviation at Downey and impact test facility	90
Command module full-scale mockup, interior and exterior	91
Little Joe II prime contractor's program manager talks with NASA officials	93
Comparison of Little Joe II and Saturn launch vehicles	93
White Sands Test Facility	93
Pad abort test at White Sands and Boilerplate 6 after impact	93
Command module structure and fabrication	95
Parachute recovery system	96
Bell's lunar landing research vehicle	109
Congressman Miller examines model of Grumman's lunar module	115
New astronauts watch Mercury liftoff	116
Mercury, Gemini, and Apollo spacecraft and launch vehicle configurations	118
GE employees monitor test in automatic-checkout-equipment control room	120
Apollo tracking network, Canberra radar antenna, and communications with the moon	124
George Mueller briefs President Kennedy	131
Lunar module extraction from adapter	132
Full-scale model of command module	134
Launch escape system and jettison	134
Full-scale mockup of service propulsion module	134
Probe and drogue assembly for docking	137
Command and service module mockup review	139
SA-6 and Boilerplate 13 ready for launch	142
Lunar module evolution, 1962-1969; docked models; and LM components	145
Proposed LM crew positions for landing, sleeping	150
Lunar module adds ladder and other improvements, fits into adapter	153
Test model 1, lunar module mockup, with propulsion system engines	162
Cutaway drawings of command module	170
Probe sensor on LM landing gear	173
Spacesuit and backpack, 1965 version	178
F-1 engine at Rocketdyne	184
Saturn V first stage at Michoud, arriving at Marshall, and fired in ground test ...	184
Mission Control Center, the mission operations control room, and Manned Spacecraft Center, 1965	186
Apollo program funding, fiscal 1960-1967	190
Apollo-Saturn 201 mission	192
J-2 engines and Saturn's S-II and S-IVB stages	195
First Saturn V rollout	196
Spacecraft 012 at North American and arriving at Kennedy Space Center	210
Workchart for CM-012	210
Astronauts Grissom, Chaffee, and White check headgear for AS-204	210
Command module 012 after January 1967 fire	216
Command module dual hatch and unified single hatch	226
X-ray inspection of harness wiring	226
Tools are replaced in accountability kit	226
Apollo 4 poised for first Saturn V mission	233
<i>Super Guppy</i>	243

CHARIOTS FOR APOLLO

	Page
Lunar module 1 in preparation for flight on Apollo 5	243
Launch Complex 39 was not on the Cape	246
Mouth of the Colorado River photographed from <i>Apollo 6</i>	249
Crew of first manned Apollo flight practices recovery	264
Command module mission simulator	264
Test vehicle in environment simulation chamber	264
<i>Apollo 7</i> , first manned Apollo flight	270-271
<i>Apollo 8</i> circles the moon	282-283
Spacecraft docking devices	288
McDivitt and Schweickart practice in the LM simulator	291
LM pilot wearing backpack	291
<i>Apollo 9</i> evaluates the LM in orbit	296-297
<i>Apollo 10</i> , dress rehearsal for the landing	308-309
<i>Apollo 10</i> crew meets the press	312
Aldrin and Armstrong practice lunar surface activities	321
Training for Apollo 11, with simulators, one-sixth gravity trainer, and lunar landing training vehicle	325
Plaque on lunar module landing gear	331
Off-loading rehearsal of the Mobile Quarantine Facility	335
Lunar Receiving Laboratory	335
<i>Apollo 11</i> lands men on the moon	350-351
Travelers to the moon return	356-357
Launch Complex 39 dedication plaque	366

Foreword

The story of Apollo is a remarkable chapter in the history of mankind. How remarkable will be determined by future generations as they attempt to assess and understand the relationship and significance of the Apollo achievements to the development of mankind. We hope that this book will contribute to their assessments and assist in their judgments.

Writing the history of Apollo has been a tremendous undertaking. There is so much to tell; there are so many facets. The story of Apollo is filled with facts and figures about complex machines, computers, and facilities, and intricate maneuvers—these are the things with which the Apollo objectives were achieved. But a great effort has also been made to tell the real story of Apollo, to identify and describe the decisions and actions of men and women that led to the creation and operation of those complex machines.

The flights of Apollo were the focus of worldwide reporting and attention. The success of these flights is directly attributable to the less well reported and less visible work of nearly 400 000 people in hundreds of different organizations. That the efforts of so many could be organized and coordinated so effectively is a tribute to American ingenuity and management abilities. Moreover, only those who were directly involved can fully appreciate the dedication, competence, courage, teamwork, and hard work of those people.

It is not possible to single out any one or even a few of the many people and the countless decisions, actions, and key events in the program as being more critical or important than the others in determining its ultimate success. Nor is it appropriate to do so since that success could not have been achieved without having first succeeded in building effective teamwork in an environment where every task, no matter how seemingly insignificant at the time, in some way affected the ultimate outcome of the program.

CHARIOTS FOR APOLLO

It was a rare personal privilege for me to serve in the Apollo program. The greatest reward was the opportunity to work with the many people in government, industry, and other organizations in this country and around the world who played a part in this tremendous undertaking. Words cannot adequately describe the extraordinary ingenuity and selfless devotion that were so often displayed by so many in surmounting the multitude of problems and obstacles that developed along the way. This program surely demonstrated what our great country can accomplish when the national will and leadership steadfastly support a competent and dedicated group of people who are unwaveringly committed to attaining a seemingly unattainable objective.

I hope that this book will not only serve future generations as they view the Apollo story in a historical perspective, but will also bring the satisfaction of a job well done to all those who served in the Apollo program.

December 1978

SAMUEL C. PHILLIPS
General, USAF (Ret.)

Preface

Apollo was America's program to land men on the moon and get them safely back to the earth. In May 1961 President Kennedy gave the signal for planning and developing the machines to take men to that body. This decision, although bold and startling at the time, was not made at random—nor did it lack a sound engineering base. Subcommittees of the National Advisory Committee for Aeronautics (NACA), predecessor of the National Aeronautics and Space Administration (NASA), had regularly surveyed aeronautical needs and pointed out problems for immediate resolution and specific areas for advanced research. After NASA's creation in October 1958, its leaders (many of them former NACA officials) continued to operate in this fashion and, less than a year later, set up a group to study what the agency should do in near-earth and deep-space exploration. Among the items listed by that group was a lunar landing, a proposal also discussed in circles outside NASA as a means for achieving and demonstrating technological supremacy in space. From the time Russia launched its first Sputnik in October 1957, many Americans had viewed the moon as a logical goal. A two-nation space race subsequently made that destination America's national objective for the 1960s.

America had a program—Project Mercury—to put man in low-earth orbit and recover him safely. In July 1960 NASA announced plans to follow Mercury with a program, later named Apollo, to fly men around the moon. Soon thereafter, several industrial firms were awarded contracts to study the feasibility of such an enterprise. The companies had scarcely finished this task when the Russians scored again, orbiting the first space traveler, Cosmonaut Yuri Gagarin, on 12 April 1961. Three weeks later the Americans succeeded in launching Astronaut Alan Shepard into a suborbital arc. These events—and other pressures to “get America moving”—provided the popular, political, and technological foundations upon which President Kennedy could base his appeal for support from the Congress and the American people for the Apollo program.

CHARIOTS FOR APOLLO

Because of its accelerated pace, high technology, and need for reliability, Apollo's costs were high (expected to be \$20 billion to \$40 billion as early as mid-1961), but the program lasted longer (albeit with aliases) than either Mercury or Gemini. (Gemini began in December 1961 to bridge some technological gaps and to keep America in space between the simpler Mercury flights and the more ambitious Apollo missions.) Requiring seven years of development and test before men could fly its machines, Apollo craft carried men into space from October 1968 through July 1975. The Apollo program itself recorded its final return from the moon on flight 17 in December 1972, after a dozen men had made six successful explorations on the lunar surface. Shortly thereafter Skylab, using the basic Saturn launch vehicle and Apollo spacecraft hardware, sailed into earth orbit, supporting crews on research missions up to 84 days in length during 1973 and 1974. Apollo passed from public view in July 1975, following the Apollo-Soyuz Test Project flight, flown by American astronauts and Russian cosmonauts to make the first international space rendezvous.

The Apollo story has many pieces: How and why did it start? What made it work? What did it accomplish? What did it mean? Some of its visible (and some not so visible) parts—the launch vehicles, special facilities, administration, Skylab program, Apollo-Soyuz Test Project, as examples—have been recorded by the NASA History Office and some have not.* A single volume treating all aspects of Apollo, whatever they were, must await the passage of time to permit a fair perspective. At that later date, this manuscript may seem narrow in scope—and perhaps it is. But among present readers—particularly those who were Apollo program participants—there are some who argue that the text is too broad and that their specialties receive short shrift. Moreover, some top NASA leaders during Apollo's times contend, perhaps rightly, that the authors were not familiar with all the nuances of some of the accounts set down here.

Chariots for Apollo: A History of Manned Lunar Spacecraft begins with the creation of NASA itself and with the definition of a manned space flight program to follow Mercury. It ends with *Apollo 11*, when America attained its goal of the 1960s, landing the first men on the moon and returning them to the earth. The focal points of this story are the spacecraft—the command and service modules and the lunar module.

The 14 chapters cover three phases of spacecraft evolution: defining and designing the vehicles needed to do the job, developing and qualifying (or certifying) them for the task, and operating them to achieve the objective. Like most large-scale research and development projects, Apollo began haltingly. NASA, with few resources and a program not yet approved, started slowly. Ad hoc committees and the field centers studied, tested, reported, and suggested, looking for the best way to make the voyage. Many

* See "The NASA History Series" at the back of this book.

aerospace industrial firms followed the same line, submitting the results of their findings to NASA and hoping to get their bids in early for a piece of the program.

When lunar landing became the Apollo objective in May 1961, the United States had only 15 minutes of manned flight experience in space and a tentative plan for a spacecraft that might be able to circumnavigate the moon. No rocket launch vehicle was available for a lunar voyage and no route (mode) agreed on for placing any kind of spacecraft safely on the lunar surface and getting it back to the earth. Nor was there agreement within NASA itself on how it should be done. But the luxury of time for committees to debate, thrash out, and reconcile differences vanished all too quickly—although NASA still had too few people and resources with which to do anything else. The agency awarded contracts for development of the systems—command module, guidance and navigation, and launch facilities—that were likely to change least when subsequent decisions were finally made. The first two chapters are devoted to these discussions.

Resolving the mode question was perhaps the most difficult decision of the entire program. The debate occupied NASA (and touched off arguments from other governmental agencies and from industry) for 18 months. General agreement on this pivotal part of the Apollo mission was essential for the selection and development of both the Saturn V launch vehicle and the lunar module that completed the Apollo hardware “stack.” Passions among the participants in the mode battle appeared violent, even divisive; but when the lunar orbit rendezvous mode was eventually selected, in July 1962, the centers and Headquarters groups closed ranks behind the decision. Chapter 4 concludes the difficult definition phase of the program.

Apollo's middle years are covered in Chapters 5 through 9. When the development and qualification phase began, the lunar module was a year behind the command module, even though there were two versions of the CM: “Block I,” limited to earth-orbital operations, and “Block II,” equipped for lunar-orbital rendezvous. At the same time, NASA was staffing and organizing to manage the complex program and drafting detailed specifications, from the smallest component to the largest subsystem. Spacecraft development took two years, lasting much longer and meeting more difficulties than expected, and caused manufacturing delays. By 1965, Apollo managers were able to spell out the tests and reviews needed to qualify the spacecraft and get it to the launch site. All this time, the managers were fighting the extra kilograms that engineering improvements were adding to the two machines. Toward the end of the year and throughout 1966, Apollo moved ahead, with Gemini and NASA's unmanned lunar reconnaissance programs supplying some answers to Apollo planners, especially about astronauts living and working in space, the ability to rendezvous, and the composition of the lunar surface. Just when mission planning and launch schedules had assumed some firmness, a spacecraft fire on the launch pad

CHARIOTS FOR APOLLO

during a routine test killed three astronauts and caused a wrenching reappraisal of Apollo program plans and much rework of the space vehicles.

Many deficiencies in the early model of the Apollo command module were eliminated as work on the advanced version progressed. When the command module was ready for its first trial flights, the lunar module was still a year behind because of propulsion, corrosion, wiring, and weight problems. NASA flight-tested both the lunar module, with all its problems, and the Saturn V, which had developed unwanted "pogo-stick" oscillations, and then decided that neither could yet be trusted to carry men into space. While solving these problems, NASA pushed ahead to qualify the command module, launching it into earth orbit (with the first Apollo crew aboard) on the smaller Saturn IB in October 1968. A daring circumlunar voyage in December not only qualified the command module for its ultimate mission but demonstrated that the Saturn V was at last trustworthy. Only the lunar module still lagged. But early 1969, the last year allowed by Kennedy's challenge, brought two flights in quick succession—one in earth orbit and the other in lunar orbit—employing all the lunar-oriented vehicles and certifying that Apollo was ready to land men on the moon. The world then watched—via television—as its first representatives walked on the surface of the moon in July 1969. These dramatic missions are discussed in Chapters 10 through 14.

This book is the work of three authors: Courtney Brooks, James Grimwood, and Loyd Swenson.* Brooks focused on the history of the lunar module, the mode issue, the search for an adequate launch vehicle, and the selection and training of astronauts (including spacesuits and training devices). Swenson examined the command module story, guidance and navigation, the command module fire, and scientific concerns. Grimwood wrote the five chapters on the Apollo missions and revised the drafts.

Sally D. Gates, Johnson Space Center History Office Editor-Archivist, served indispensably in many capacities in preparing this history: research assistant, editor, coordinator of the comment draft, compiler of the appendixes, typist, proofreader, and critic. Contributions en route were made by Billie D. Rowell, Corinne L. Morris, and Ivan D. Ertel, all former members of this office. Rowell and Morris worked on the archives, and Ertel selected the illustrations. Verne L. Jacks, an employee of the University of Houston, transcribed some of the taped oral history interviews and typed several trial draft chapters.

As may be seen in the source notes, the text rests on primary Apollo program documentation on the spacecraft. The archival base (about 25 cabinets of documents) was extensive, and the authors owe the program participants a great debt for heeding the admonition, "Don't throw away history!" Melba S. Henderson provided the Apollo Spacecraft Program

* See Authors page at the back of the book for biographical sketches.

PREFACE

Office reading files, which contained the day-to-day record of the worries and joys of managers and engineers as Apollo progressed. A host of others—most of whose names are in the notes—gave up treasured desk archives and illustrations. More than 300 of these participants agreed to taped oral history interviews.

Although this book was written under the auspices of the NASA history program, partially through a contract with the University of Houston, the contents are the judgments of its authors and in no way represent a consensus of NASA management—if such a thing were possible—about any of the topics, programs, actions, or conclusions. Like many who write contemporary history, the present chroniclers found far more advantages than hazards in having the counsel of the participants in weighing the mass of evidence and clearing the technical points. This assistance proved invaluable, though many who provided aid would not agree with the authors' selections and presentations—and some have said as much. Special mention should also be made of the help received from the NASA History Office—Monte D. Wright, Frank W. Anderson, Jr., Lee D. Saegesser, Carrie E. Karegeannes, and Alex F. Roland; from former NASA Historian Eugene M. Emme; and from the Chief of Management Analysis at the Johnson Space Center—Leslie J. Sullivan. But the authors alone must shoulder the responsibility for any defects the text may still contain.

C.G.B.
J.M.G.
L.S.S.

Houston
September 1978

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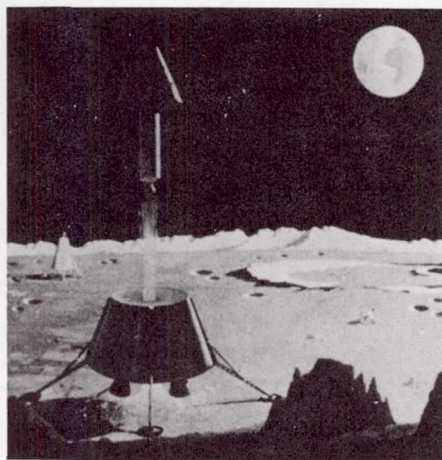
Concept to Challenge

1957 to Mid-1961

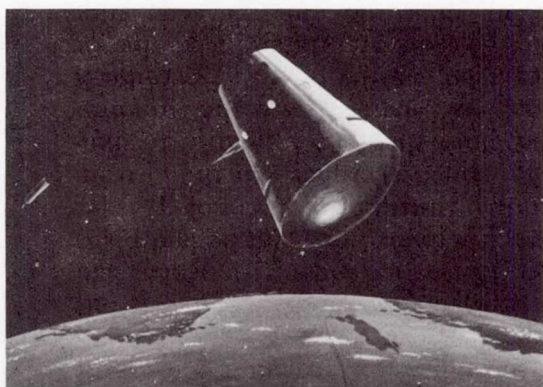
The orbiting of *Sputnik I* in October 1957 stirred the imagination and fears of the world as had no new demonstration of physics in action since the dropping of the atomic bomb. In the United States the effect was amplified by realization that the first artificial satellite was Russian, not American. Yet the few scientists and engineers working in Project Vanguard and other U.S. space projects were surprised only at the actual timing. Indeed, they had already considered means of sending man around the moon.

Modern rocket technology dates from the Second World War; the development of intercontinental ballistic missiles in succeeding years resulted in machines that could eventually launch vehicles on space missions. In this same time, man's flying higher, faster, and farther than ever before suggested that he could survive even in space. *Sputnik I* caused alarm throughout the United States and the ensuing public clamor demanded a response to the challenge.¹ During the next year, many persons in government, industry, and academic institutions studied means and presented proposals for a national space program beyond military needs. After decades of science fiction, man himself, as well as his imagination, moved toward an active role in space exploration.

Concurrently with the formation of the National Aeronautics and Space Administration (NASA) in late 1958—a year after the first *Sputnik*²—a proposal (which became Project Mercury) was approved to fly man in near-earth orbit.³



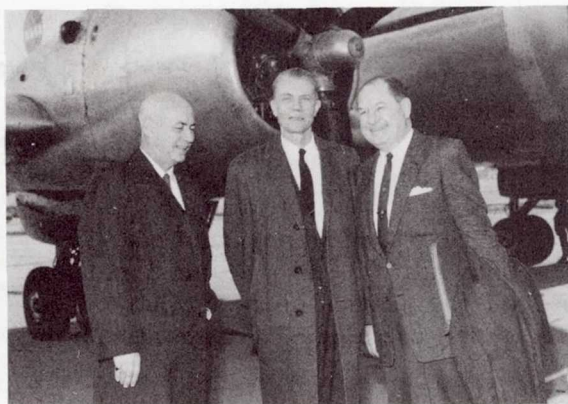
Artist's concepts sketched about February 1959 were used in a presentation by M. W. Rosen and F. C. Schwenk at the Tenth International Astronautical Congress in London, 31 August 1959. Above, astronauts leave the spacecraft to investigate the lunar surface. At right, the return vehicle takes off from the moon; below, the reentry vehicle begins to enter the atmosphere after jettisoning the propulsion unit.



FORGING A NATIONAL SPACE AGENCY

The National Aeronautics and Space Act of 1958, passed by Congress in July of that year, said nothing about the moon or manned space flight. In its declaration of policy and purpose, however, the general objectives were to improve and use aeronautical and space capabilities "for the benefit of all mankind." If achieving international leadership in space meant that this nation would have to fly men to the moon, the Act encouraged that ambition.⁴ Clearly NASA, as the nonmilitary agency of the United

Space Task Group Director Robert R. Gilruth, left, and Langley Research Director Floyd L. Thompson, center, welcome NASA Administrator T. Keith Glennan to Langley Field, Virginia, for a January 1961 tour.



States, would be responsible for furthering the national interest in space affairs. But the new agency required more than just a charter before the President and the Congress could turn it loose on a task requiring a vast acceleration of activity and a large commitment of national resources.

Much of the preliminary planning for Project Mercury had been done by the National Advisory Committee for Aeronautics (NACA), NASA's predecessor. NASA's first Administrator, T. Keith Glennan, president of Case Institute of Technology (on leave), set about organizing and using the heritage of experience and resources that had carried Mercury from the planning stage into actuality. His deputy, Hugh L. Dryden (former Director of NACA), planned and executed policy decisions during NASA's first few years. Abe Silverstein, who came from NACA's Lewis Flight Propulsion Laboratory in Cleveland, was assigned by Glennan to manage a coordinated program for a stable of rocket boosters to suit a variety of space missions.⁵

The White House had approved plans to develop big boosters, but Glennan knew that would not be enough. He wanted organizations that had participated in developing these vehicles, and toward this end he laid plans for the eventual transfer of the California Institute of Technology's Jet Propulsion Laboratory (JPL) and of the Army's Wernher von Braun team (Army Ballistic Missile Agency; ABMA) into the NASA family. In January 1959, Wesley L. Hjornevik, Glennan's assistant, pressed the Administrator to "move in on ABMA in the strongest possible way . . . because it is becoming increasingly clear that we will soon desperately need this or an equivalent competence." Although JPL came into the fold soon after the agency opened for business, a year and a half passed before Glennan persuaded the Eisenhower administration to consign a portion of ABMA and some of its facilities, later named the George C. Marshall Space Flight Center, to NASA.⁶

In addition to the oldest NACA laboratory—at Langley Field, Virginia, across Hampton Roads from Norfolk—and the other two NACA laboratories—Ames, at the lower end of San Francisco Bay, and Lewis, in Cleveland—

CHARIOTS FOR APOLLO

NASA inherited the NACA authorization to build a center for development and operations. Dryden was well aware of the applied research character of Langley, Ames, and Lewis. He was anxious to insulate these former NACA centers from the drastic changes that would come while shifting to actual development in NASA's mission-oriented engineering. Space science, mission operations, and, particularly, manned space flight should, he thought, be centralized in the new facility to be built near Greenbelt, Maryland. To direct Project Mercury, Glennan established the Space Task Group, a semiautonomous field element under Robert R. Gilruth. When the new center was completed, the Mercury team would move to Maryland.* In May 1959, Glennan announced that this new installation would be called the Goddard Space Flight Center in commemoration of Robert H. Goddard, the American rocket pioneer.⁷

Besides the NACA personnel, programs, and facilities, NASA acquired, by transfer, ongoing projects from the Army (Explorer), Navy (Vanguard), and Air Force (F-1 engine).⁸ These were worthwhile additions to the new agency; to comply with the language and intent of the Space Act, however, NASA had to plan a long-range program that would ensure this country's preeminence in space exploration and applications.

THE STARTING

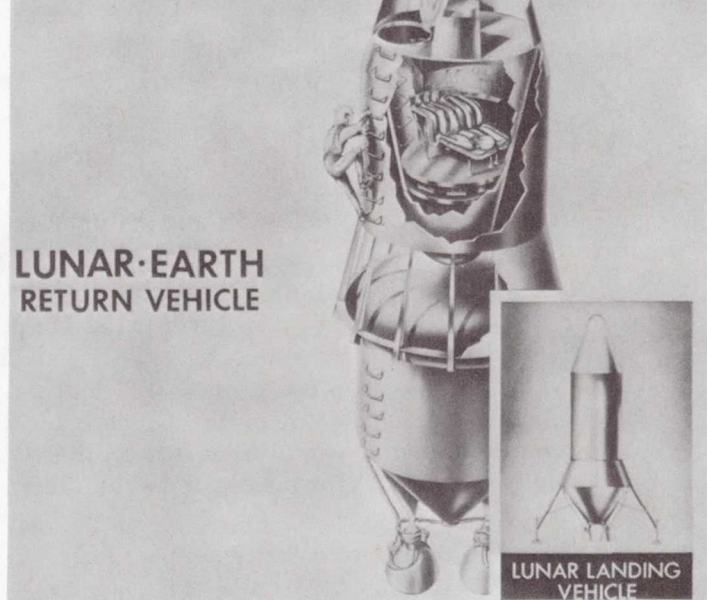
As part of its legacy NASA inherited the insight of an ad hoc Space Technology Committee into what some of its research goals should be. At the behest of James H. Doolittle, Chairman of NACA's Main Committee, in February 1958 H. Guyford Stever of the Massachusetts Institute of Technology had headed a group that examined a wide variety of possible space projects, giving NACA needed guidance for research into space technology. Exploration of the solar system was seen as an arena where man, as opposed to mere machines, would definitely be needed. When NASA opened for business in October 1958, this recommendation in the Stever Committee's final report gave the new agency a start on its basic plans.⁹

Sending men beyond the earth's gravitational field, however, required launch vehicles with weight-lifting capabilities far beyond that of the Atlas, the only American missile that could lift the small Mercury spacecraft into earth orbit. Moreover, there was nothing being developed and very little on the drawing boards that could carry out the Stever Committee's suggestion. Glennan was therefore willing to listen to anyone who might provide a sensible booster development plan. On 15 December 1958, he and

* In May 1959, Glennan also appointed Gilruth Assistant Director for Manned Satellites at Goddard. Harry J. Goett was named Director of the new center in September.

A lunar-earth return vehicle as envisioned at the Army Ballistic Missile Agency in early 1960 was drawn for Wernher von Braun's use in an ABMA study, "A Lunar Exploration Program Based upon Saturn-Boosted Systems."

LUNAR-EARTH RETURN VEHICLE



his staff sat in their headquarters in the Dolley Madison House in Washington to be briefed by missile development leaders from ABMA. Wernher von Braun and two associates, Ernst Stuhlinger and Heinz H. Koelle, surveyed the capabilities of current and planned boosters, their utility for various space missions, and ABMA's work on launch vehicle design and operation. In essence, they described how their agency might play a leading role in America's national space program.¹⁰

The theme of these presentations was manned landings on the moon. Koelle emphasized the need for a few versatile space vehicles, rather than a plethora of different models. ABMA offered a program for building a family of these rockets. Koelle predicted that perhaps by the spring of 1967 "we will have developed a capability of putting . . . man on the moon. And we still hope not to have Russian Customs there." He stressed how neatly ABMA's launch vehicle program complemented NASA's emerging manned space flight activity. "The man-in-space effort," he said "dovetails with the lunar and cislunar activities because you simply can't land a man on the moon before you have established a man-in-space capability; that is quite clear."¹¹

Von Braun said ABMA preferred clustering engines in launch vehicles, emphasizing that the multiengine concept of aviation was directly applicable to rockets. Next he talked about plans for a multistage Juno V—suggesting different propellants for particular stages—the most ambitious rocket ABMA then contemplated.

To answer, "What will it take to get people to the surface of the moon and back?" von Braun described five techniques, direct ascent and four kinds of rendezvous en route. Assuming the feasibility of high-energy (liquid-hydrogen and liquid-oxygen) upper stages and a capsule conservatively estimated at 6170 kilograms, for direct ascent "you would need a seven-stage vehicle which weighed no less than 13.5 million pounds [6.1

CHARIOTS FOR APOLLO

million kilograms].” Developing and flying such a rocket was forbidding to von Braun.

Instead of this enormous vehicle, he suggested launching a number of smaller rockets to rendezvous in earth orbit. He proposed using 15 of these, which “it just so happens,” he said, wryly, “had the size and weight of the Juno V.” These boosters could place sufficient payload in orbit to assemble a vehicle of some 200 000 kilograms, which could then depart for the moon. The lunar-bound craft would be staged on the way, dropping off used tanks and engines as the flight progressed—“in other words, leave some junk behind.”¹²

Next, Stuhlinger rose and said:

The main objective in outer space, of course, should be man in space; and not only man as a survivor in space, but man as an active scientist, a man who can explore out in space all those things which we cannot explore from Earth.

He catalogued the unknowns of space vehicle components and research objectives in materials and in protection against space hazards. What happens, for instance, to metals, plastics, sealants, insulators, lubricants, moving parts, flexible parts, surfaces, coatings, and liquids in outer space? How could we guard men and materials from the dangers of radiation, meteorites, extreme temperatures, corrosion possibilities, and weightlessness? What kinds of test objectives, in what order and how soon, should be established? “We . . . are of the opinion that if we fail to come up with answers and solutions to [these] problems, then our entire space program may come to a dead end, even though we may have the vehicles to carry our payloads aloft.”¹³ Although Glennan was impressed, he knew that NASA’s first tasks were Mercury and the giant F-1 rocket engine.

Congress had been seeking some consensus of what the nation should do in space. At the beginning of 1959, the House Select Committee on Astronautics and Space Exploration released a staff study, *The Next Ten Years in Space*, reporting a poll of the aerospace community on the direction of America’s space program through the 1960s. Prominent among projected manned programs beyond Mercury was circumlunar flight. Those queried spoke confidently of this goal, saying it was only a question of time. Not a single spokesman doubted the technical feasibility of flying around the moon. Predictions spanned the latter half of the decade, with expectations that manned lunar landings would follow several years later.¹⁴

Glennan and Dryden, responding to congressional inquiry, subscribed to this belief. They outlined NASA’s plans in space sciences, the application of space capabilities to the national welfare, and research and development in advanced space technology. “There is no doubt that the Nation has the technological capability to undertake such a program successfully,”

CONCEPT TO CHALLENGE

they said. "There is a good chance that [within ten years] space scientists may have circumnavigated the Moon without landing and an active program should be underway to attempt a similar flight to Venus or Mars. . . . Manned surface exploration will be receiving serious research and development effort."¹⁵

The NASA Administrator immediately asked for funds to begin designing and developing a large booster, the first requirement for space exploration. At the end of January 1959, NASA submitted to President Dwight D. Eisenhower a report on "A National Space Vehicle Program," in which the agency proposed four boosters, Vega, Centaur, Saturn, and Nova.*

These rockets were expected to fulfill all foreseeable needs during the next decade. Although Vega and Nova barely progressed beyond the drawing board, all four were basic concerns for some time. Listed here in order of their envisioned power, only the high-energy Centaur and the multi-staged and clustered Saturn systems were to be developed. During January and February of 1959, the von Braun team's Juno V gained substantial backing and emerged with a new name, becoming the first in the Saturn family of rockets.¹⁶

NASA's research centers also had done some preliminary thinking about what should follow Project Mercury. In the spring of 1959 Glennan, wanting to encourage that thinking, created a team to study advanced missions and to report its findings to him. The Goett Committee became one of the foremost contributors to Apollo.

THE GOETT COMMITTEE

On 1 April 1959, NASA Headquarters called for representatives from its field centers to serve on a Research Steering Committee for Manned Space Flight, headed by Harry Goett, an engineering manager at Ames who became Director of the new Goddard center in September. Goett and

* Vega and Centaur were upper stages for launch vehicles. The Vega was either one or two stages (depending on the payload to be lifted or moved about in space) and used conventional fuels. Toward the end of 1959, Vega was canceled because it was too similar to the Air Force Agena. NASA continued development of the Centaur upper stage because of its more exotic propellants, hydrogen and oxygen, which promised lifting power far beyond the weight of its fuel load—about 40 percent greater than possible with conventional rocket fuels like kerosene. It was not until 1966 that the agency had some confidence that the vehicle could be trusted for manned flights.

Saturn and Nova were multistage launch vehicles, not clearly defined during NASA's first three years and often described in ways that made it difficult to tell which was which (see page 47). Some Apollo program participants contend that the Saturn V, eventually selected, was very close to what would have been a Nova had the agency chosen it.

CHARIOTS FOR APOLLO

nine others* began their deliberations in Washington on 25 May. Milton W. Rosen, NASA Chief of Propulsion Development, led off with a report on the national booster program. Next, representatives of each center described the status of work and planning toward man-in-space at their respective organizations.¹⁷

Laurence K. Loftin, Jr., said that 60 percent of Langley's effort pertained to space and reentry flight research; Maxime A. Faget, of the Space Task Group, discussed Mercury's development. Alfred J. Eggers, Jr., told the group what Ames was doing and then advocated that NASA's next step be a spacecraft capable of flying two men for one week, with enough speed to escape the earth's gravitational pull, fly to the moon, orbit that body, and return to the earth.

Bruce Lundin described propulsion and trajectory studies under way at Lewis and warned against "setting our sights too low." As Glennan and Dryden had done, Lundin took a broad view of space exploration, reminding the committee that a manned lunar landing was merely one goal, leading ultimately to manned interplanetary travel.

It was apparent that NASA leaders intended to aim high. Faget, one of the inventors of the Mercury capsule, and George Low urged manned lunar landings as NASA's next objective. Low stressed study of ways to perform the mission, using several of the smaller Saturns in some scheme besides direct ascent to avoid total dependence upon the behemoth that Nova might become. The Goett Committee then recorded its consensus on the priority of NASA objectives:

1. Man in space soonest—Project Mercury
2. Ballistic probes
3. Environmental satellite
4. Maneuverable manned satellite
5. Manned space flight laboratory
6. Lunar reconnaissance satellite
7. Lunar landing
8. Mars-Venus reconnaissance
9. Mars-Venus landing¹⁸

The next meeting of the Goett Committee was at Ames 25–26 June. Going into details about technical problems and their proposed solutions as seen from different pockets of experience around the country, the members heartily endorsed moon landing and return as NASA's major long-range manned space flight goal. As Goett later remarked:

* Goett's committee consisted of Alfred J. Eggers, Jr. (Ames), Bruce T. Lundin (Lewis), Loftin (Langley), DeElroy E. Beeler (High Speed Flight Station), Harris M. Schurmeier (JPL), Maxime A. Faget (Space Task Group), and George M. Low, Milton B. Ames, Jr., and Ralph W. May, Jr., secretary (Headquarters). Ames was a part-time member.

CONCEPT TO CHALLENGE

A primary reason for this choice was the fact that it represented a truly end objective which was self-justifying and did not have to be supported on the basis that it led to a subsequent more useful end.¹⁹

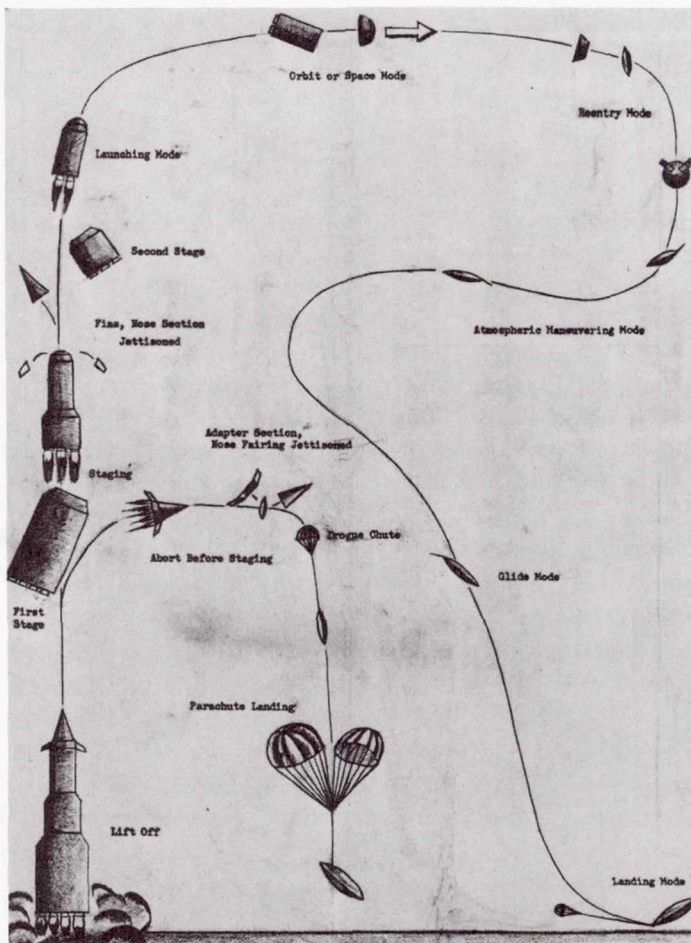
At this meeting, the Goett Committee members compared direct ascent with rendezvous in earth orbit. At Low's request, John H. Disher first reviewed the sizable activity at Huntsville. In February 1959, the Department of Defense had announced that development of the 5800-kilonewton (1.3-million-pound-thrust) rocket had been designated Project Saturn. Less than six months later, Disher reported, the von Braun group already had its sights set on a Saturn II (a three-stage version with an 8900-kilonewton [2-million-pound-thrust] first stage) and rendezvous in earth orbit, even working on some modes that called for refueling in space. Von Braun's team was also studying a Nova-class vehicle for direct ascent.

Lundin then made some disquieting comments. For direct flight to the moon, propulsion needs were staggering. Even with cryogenic propellants in the upper stages of the launch vehicle, the combined weight of rocket and spacecraft would be about 4530 to 4983 metric tons—a formidable size. He also noted that prospects for earth-orbital rendezvous seemed little brighter; such a procedure (launching more than a dozen Saturn-boosted Centaurs to form the lunar vehicle) required complex rendezvous and assembly operations. Lundin ticked off several areas that would need further study, regardless of which mission mode was chosen: cryogenic storage in space, a throttleable lunar-landing engine, a storable-propellant lunar-takeoff engine, and auxiliary power systems.*²⁰

On 8 and 9 December 1959 at Langley, Goett's group met for the third (and apparently last) time. The main discussions centered on lunar reentry heat protection, all-the-way versus assembly-in-orbit, parachute research, environmental radiation hazards, and the desirability of or necessity for a manned orbiting laboratory. Most of the field center studies were predicated on a two-man, 14-day circumlunar flight, boosted by some sort of Saturn vehicle and protected by ablative shielding. Very little specific thought, however, had been given to the actual lunar landing.²¹

Opinion within the committee on what NASA's next (as opposed to its long-range) program should be had been far from unanimous, however. Langley, which by this time had begun extensive studies of space station

* Cryogenic fuels are corrosive and are difficult to store for any length of time because of the low temperatures required to maintain the proper state of the oxidizer—in this case, liquid oxygen. This fuel, moreover, requires the extra complication of an igniter to fire it. A throttleable engine is one that can be started and stopped as needed. Storable propellants are hypergolic fuels that ignite on contact with the oxidizer, demand no special temperature controls, are not corrosive, and can remain in storage indefinitely. The power systems Lundin talked about were fuel (or solar) cells that could generate the electrical energy needed on long flights without the weight penalties attached to the more conventional batteries used in Mercury.



Using a lenticle-shaped spacecraft for a reentry vehicle.

concepts and related problems including rendezvous, strongly favored earth-orbital operations.* Faget was allied with Langley, because the Space Task Group was greatly concerned about the unknowns in lunar operations, especially radiation. But Goett and Low remained unswerving in their advocacy of lunar flight. They insisted that the technology for flying to the moon could be applied to near-earth missions, but not vice versa. Indeed, Low perhaps more than any other pushed for landing rather than just circumlunar flight, but neither the committee as a whole nor the chairman

* On the instigation of E. C. Braley and Loftin, Langley had held a conference on 10 July 1959 to study the aspects of placing a manned space laboratory in operation. This project was seen as a step to the eventual landing of a man on the moon in 10 to 15 years.

CONCEPT TO CHALLENGE

was willing to go that far. "In fact," Low later said, "I remember Harry Goett at one time was asked, 'When should we decide on whether or not to land on the moon? And how will we land on the moon?' And Harry said, 'Well, by that time I'll be retired and I won't have to worry about it.' " ²²

Although the time had come for someone in authority to start making the decisions that could lift the moon mission out of the realm of research and start it on the path toward development, Glennan could not commit the agency to any specific long-range programs, especially lunar flight. Knowing that the President's intent to "balance the budget, come hell or high water," would preclude anything beyond Project Mercury just then, Glennan bided his time. Without executive approval, NASA could only continue its studies and wait for a more propitious moment.²³

FOCUSING THE AIM

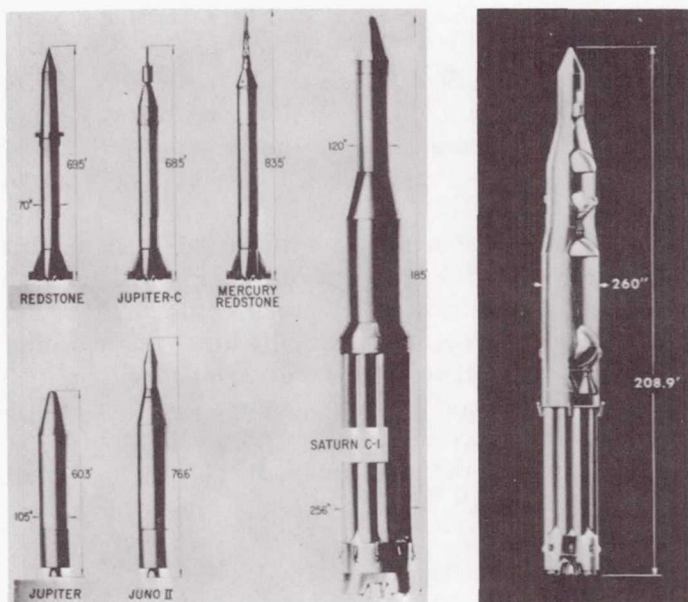
The Goett Committee did only what it was set up to do—study possible options and suggest objectives that NASA might pursue—but its findings did focus attention on manned circumlunar flight. Well before the committee discontinued its meetings, small groups at nearly all of the field centers had taken the initiative and started research toward that goal.

For example, during the summer of 1959, Gilruth formed a New Projects Panel within the Space Task Group under H. Kurt Strass.* Meeting twice in August, the panel members identified a number of areas for research and recommended that work begin immediately on an advanced manned capsule, a second-generation spacecraft crewed by three men and capable of reentering the atmosphere at speeds nearly as great as those needed to escape the earth's gravitational pull. The group was clearly planning a lunar spacecraft. Convinced that this should be the Space Task Group's next major project, the members further agreed that manned lunar *landing* should be the goal to design toward, and they assumed 1970 as a suitable target date.²⁴

At the third meeting of the panel, on 28 September, Alan Kehlet presented some ideas for a lenticular reentry vehicle. (Later, he and William W. Petynia worked out enough details to apply for a patent on a capsule that appeared to be formed by two convex lenses and looked like a flying saucer.)²⁵

The thinking of the New Projects Panel—and that was all Gilruth intended it to do, think—may have been premature, but it pointed out the

* The members of the Strass group were Alan B. Kehlet, William S. Augerson, Robert G. Chilton, Jack Funk, Caldwell C. Johnson, Jr., Harry H. Ricker, Jr., and Stanley C. White.



Evolutionary launch vehicles leading to the Saturn C-1, left, and proposed Saturn C-2, right. On 18 January 1960, the Saturn project was accorded the government's highest priority rating for development and hardware procurement.

need to raise the level and amount of manpower invested in planning advanced spacecraft systems.* At a Space Task Group management meeting on 2 November 1959, Gilruth assigned Robert O. Piland, Strass, John D. Hodge, and Caldwell Johnson to delve into "preliminary design of a multi-man (probably 3)" circumlunar spacecraft and into mission analyses of trajectories, weights, and propulsion needs.²⁶

Piland's group focused on circumlunar flight as NASA's immediate objective. The team members dealt mostly with spacecraft design, but they also dipped fairly deeply into mission analyses. They adopted the idea of flying directly from the earth to the moon's surface. Again, however, these studies by the Space Task Group at Langley were only part of similar efforts going on concurrently at NASA Headquarters, at Langley, at Ames, at Lewis, and at several industrial contractors' plants. After the thinking, the task of picking and choosing what to do would begin.²⁷

At Headquarters, toward the end of 1959, the Office of Program Planning and Evaluation, headed by Homer J. Stewart, drew up a "Ten Year

* By June of 1959 the original Space Task Group complement of 45 had grown to 367. Gilruth anticipated that the personnel requirements for fiscal year 1961 would be 909; most of the new employees would be assigned to a maneuverable manned satellite, a manned orbiting laboratory, and a manned lunar expedition.

Plan." Much of it, especially the part dealing with manned flight, evolved from the Goett Committee's priority list. In addition to a program of unmanned lunar and planetary exploration, it called for manned circumlunar flights and a permanent space station in earth orbit by the late 1960s. Lunar landings were projected for some time after 1970.

The Headquarters plan recommended developing more powerful engines and fitting them to huge Nova-class launch vehicles, as the most practical means of getting to the moon. Studies of rendezvous in space were under way as a part of the Saturn vehicle lunar mission analysis, but Stewart's group anticipated that manned lunar exploration would depend on Nova.²⁸

To clarify some of the thinking about designing manned spacecraft and missions for them, Administrator Glennan in December 1959 set up another in the long string of committees (and there would be a plethora of these before Apollo took on its final form), this time to try to define more precisely just what would make up the Saturn rocket systems. With Abe Silverstein as chairman, this group consisted of Colonel Norman C. Appold of the Air Force, Abraham Hyatt and committee secretary Eldon W. Hall of NASA, von Braun of the Army's ABMA, George P. Sutton of the Department of Defense's Advanced Research Projects Agency, and Thomas C. Muse of the Office of the Director of Defense Research and Engineering. There had been a lot of talk about what kinds of propellants to use in the vehicle's upper stages. The Lewis laboratory had researched the potentials of liquid hydrogen in combination with liquid oxygen throughout the mid-1950s. Department of Defense and NASA research was aimed at prototypes of the Centaur rocket to prove the worth of these high-energy, low-weight propellant systems. The most important result of the committee was that Silverstein and his team hammered out a unanimous recommendation that all upper stages should be fueled with hydrogen-oxygen propellants. This determination, like many others, was a significant piece of the launch vehicle puzzle.²⁹

Calendar year 1959 had been fruitful for those who saw the moon as manned space flight's next goal. NASA's leaders were coming around to that viewpoint and, on 7 January 1960 in a meeting with his staff, Glennan concurred that the follow-on program to Project Mercury should have an end objective of manned flight to the moon.³⁰ NASA had its ten-year plan to present to Congress and a reasonable assurance of getting President Eisenhower's approval to speed up the development of a large launch vehicle.

PRIMING THE PIPELINE

"You are hereby directed . . . to accelerate the super booster program for which your agency recently was given technical and management re-

CHARIOTS FOR APOLLO

sponsibility," Eisenhower wrote Glennan in January 1960. This action ensured the transfer of the von Braun group from the Army Ballistic Missile Agency to NASA,³¹ giving Glennan the launch vehicle development and management capability that he wanted.

Eisenhower's letter to Glennan was the first indication that the administration might approve something beyond Mercury. At least, Glennan interpreted it that way and told Silverstein, Director of NASA's Office of Space Flight Programs, to encourage advanced design teams at each field center and in the aerospace industry. Plans soon came in from both of those sources. In February 1960, von Braun's team distributed its latest study, "A Lunar Exploration Program Based upon Saturn-Boosted Systems."³² A month earlier, J. R. Clark of Vought Astronautics, the Dallas, Texas, division of Chance Vought Aircraft, Inc., had sent Silverstein a brochure, "Manned Modular Multi-Purpose Space Vehicle," the work, primarily, of Thomas E. Dolan. The booklet outlined a unified, systematic approach to a national space exploration program leading toward a manned lunar landing mission.³³

In early 1960, with Mercury still unproved, chances of winning administration approval to move either of these proposals (or any others that surfaced) into the hardware development stage were small. On the other hand, no one was told to stop planning a payload that might fit atop the newly approved superbooster. In fact, on 15 February 1960, Silverstein told Gilruth to "work out a presentation similar to Vought using [the] *modular concept*," which simply meant designing separate pieces of the spacecraft for specific functions at different phases of a mission. Gilruth gave this task to Piland's advanced design group, a somewhat more concrete assignment than that of the previous November.³⁴

Piland's team pulled together some guidelines and began presenting them to all the NASA centers. Piland, Faget, Stanley White, and Robert Chilton spoke, answered questions, and distributed copies of their papers on the aspects of lunar mission planning, leaving the final summary to Gilruth's Associate Director for Development, Charles J. Donlan. Donlan outlined the problems that could be foreseen and solicited "suggestions and proposals as to how best this effort can be carried out. . . . We would hope in the immediate future to obtain your views as to the problems each Center may concentrate on so that the whole NASA effort can be integrated as soon as possible."

Donlan asked specialists at the NASA centers to study such critical areas as flight duration, optimum launch times, propulsion requirements, trajectory analyses, and the effects of the moon's gravity on lunar orbits. He also cited the need for configuration studies of the lunar landing stage—"a one- or two-component lunar vehicle."³⁵

While these briefing sessions were going on, Langley sponsored a conference on space rendezvous in May 1960. Participants from all of NASA's

CONCEPT TO CHALLENGE

organizations reviewed rendezvous studies under way and discussed likely avenues for further research. Although rendezvous would be invaluable for future manned space programs, until NASA secured funds for a rendezvous flight-test program, the centers would be limited to their own ground-based experiments. Langley was already engaged in studies.³⁶ John C. Houbolt, Assistant Chief of the Dynamic Loads Division, had formed a small group to study "soft rendezvous"—or how two vehicles could come together at the high velocities required for space travel without crashing into each other.³⁷

Toward mid-1960, committees and groups within NASA had done as much preliminary internal work as was profitable; John Disher and George Low persuaded Glennan that it was time to sponsor a NASA-Industry Program Plans Conference in late July to tell of NASA's tentative plans. At one of the last briefings for this meeting, on 9 July, the Administrator approved the awarding of three feasibility contracts for advanced manned space flight studies.³⁸

Silverstein, one of those leading the charge toward more far-ranging flights than Mercury, had been looking for a suitable name for a payload for the Saturn rockets. None suggested by his associates seemed appropriate. One day, while consulting a book on mythology, Silverstein found what he wanted. He later said, "I thought the image of the god Apollo riding his chariot across the sun gave the best representation of the grand scale of the proposed program." Occasionally he asked his Headquarters colleagues for their opinions. When no one objected, the chariot driver Apollo (according to ancient Greek myths, the god of music, prophecy, medicine, light, and progress) became the name of the proposed circumlunar space-ships. At the opening of the conference on 28 July 1960, Dryden announced that "the next spacecraft beyond Mercury will be called Apollo."³⁹

On 28 and 29 July 1960, 1300 representatives from government, the aerospace industry, and the institutions attended the first in a series of NASA-industry planning sessions. During these two days, 20 NASA officials outlined the agency's plans for launch vehicle development and potential projects for manned and unmanned spacecraft. Many of the invitees returned on 30 August to learn about plans for a circumlunar manned spacecraft program and three six-month feasibility contracts to be awarded later. Briefings by the Space Task Group's top officials and planners, including Gilruth and Piland, emphasized that Apollo would be earth-orbital and circumlunar and would directly support future moon landings. Donlan wound up the afternoon with particulars of the Space Task Group's procurement plan. Any interested company would be invited to a bidders' conference in two weeks; formal proposals would be required four weeks later; and the study contracts would be awarded by mid-November.⁴⁰

Following the same general format, the bidders' briefing at Langley on 13 September included a formal request for proposal, a statement of work,



Robert Gilruth (second from left), Director of the Space Task Group, and chief assistants Charles Donlan (left), Maxime Faget, and Robert Piland in August 1960 discuss selection of contractors to study feasibility of a manned circumlunar mission.

and some definite guidelines. Essentially, these ground rules were based upon the assumption that the Saturn booster could launch a lunar reconnaissance spacecraft that would support three men for two weeks.

Piland laid out four mission and vehicle guidelines: manned lunar reconnaissance; earth-orbital missions in conjunction with a space laboratory or space station; Saturn booster compatibility (spacecraft weight not to exceed 6800 kilograms for lunar missions); and a 14-day flight time.

Faget stressed return, reentry, and landing: safe recovery from aborts; ground *and* water landings (with a capability for avoiding local hazards); 72-hour postlanding survival period; landing in preplanned locations; and auxiliary propulsion for maneuvering in space.

Richard S. Johnston presented three demands: "shirt-sleeve" environment, three-man crew, and radiation protection. He discussed the need of the crews for a safe environment and for atmospheric control.

Finally, Chilton presented guidelines for onboard command, emphasizing man's role as an active participant in the mission and its influence on hardware design, and for communications tracking, discussing the ground facilities needed for flights beyond earth orbit. Altogether, these guidelines constituted what the Space Task Group would demand of the Apollo spacecraft.⁴¹

THE FEASIBILITY STUDIES

The Space Task Group had published the formal Request for Proposal on 12 September 1960. Eighty-eight firms sent representatives to the

CONCEPT TO CHALLENGE

bidders' briefing, but only sixty-three picked up forms. By 9 October, NASA had received 14 bids.* Many aerospace firms teamed up, either in partnership or as subcontractors, to vie for the awards.

All bidders were told that even the losers should continue their efforts, thus strengthening their chances in competing for the hardware phase of Apollo. NASA assured them that the agency would not limit its choice of the designer and builder of the spacecraft to the three selected study contractors. Space Task Group people met later with representatives from the losing firms, discussed the weaknesses in their proposals, and offered to work with them informally to overcome these failings.⁴²

Donlan and contracting officer Glenn F. Bailey prepared a detailed plan for the orderly evaluation of proposals, to begin on 10 October. Five technical panels were set up, and Donlan was appointed chairman of the evaluation board. Besides Faget and Piland (with Goett and Gilruth as ex officio members), Donlan's board consisted of Disher (NASA Office of Space Flight Programs), Alvin Seiff (Ames), John V. Becker (Langley), and Koelle (Marshall).⁴³

On 25 October, after the panels had compared the bidders' proposals in trajectory analysis, guidance and control, human factors and radiation, onboard systems, and systems integration, Goett announced the winners: the teams led by Convair/Astronautics of San Diego, General Electric of Philadelphia, and the Martin Company of Baltimore. Contracts of \$250 000 were awarded to each of the three.

Convair/Astronautics operated under a more complicated arrangement than the other two winners, using its Fort Worth division for radiation and heat protection, its San Diego plant for life support studies, the Lovelace Foundation and Clinic in Albuquerque for aerospace medicine, and the Avco Corporation's Research and Advanced Development Division in Wilmington, Massachusetts, for data on reentry vehicle design. General Electric's Missile and Space Vehicle Department teamed with Bell Aerosystems Company. Martin decided to go the whole route alone.⁴⁴

Members of the Space Task Group who monitored the three study contracts developed into a fourth group, working out their own advanced designs just as the contractors were doing. Jack Funk, Stanley H. Cohn, and Alan Kehlet, for example, concentrated on trajectory analysis; Chilton, Richard R. Carley, and Howard C. Kyle studied guidance and control; Johnston, Harold I. Johnson, C. Patrick Laughlin, James P. Nolan, Jr., and Robert B. Voas investigated the human factors area; and John B. Lee, Richard B. Ferguson, and Ralph S. Sawyer looked into designs for onboard

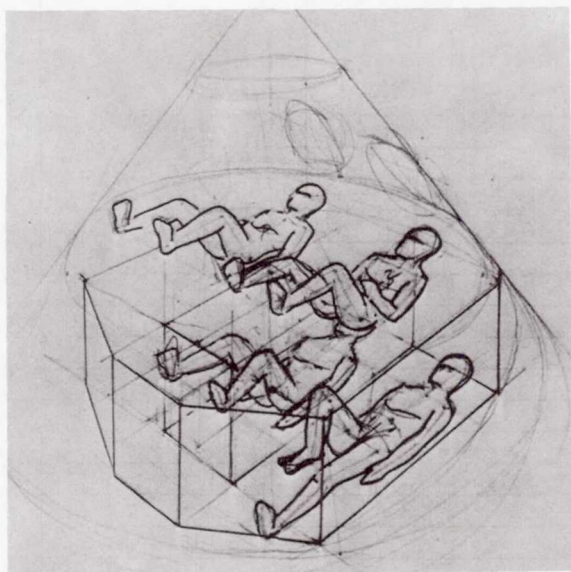
* From Boeing; Convair/Avco; Cornell/Bell/Raytheon; Douglas; General Electric/Bell; Goodyear; Grumman/ITT; Guardite; Lockheed; McDonnell; Martin; North American; Republic; and Vought.

CHARIOTS FOR APOLLO

systems. This sort of work gave them the confidence they needed to act as monitors for the study contractors and an opportunity to compare their designs with those submitted by industrial experts. Most significantly, perhaps, the systems integration crowd (members who were studying how all the pieces would fit together)—Caldwell Johnson, Owen E. Maynard, Strass, Robert E. Vale, and Kenneth C. Weston—soon decided that the Space Task Group's own preliminary design was a good one.⁴⁵

When the time came to draw up early specifications for Apollo—the technical aspects of the program—NASA Headquarters left its spacecraft and booster design people alone. The tasks of these two groups, still in the preliminary stage, were so well separated that there was no real need as yet for any arbitration of the problems that might arise when Gilruth's spacecraft group and von Braun's launch vehicle team began putting their pieces of the space vehicle together.⁴⁶

Washington had, as a matter of fact, a more pressing problem on its hands: where to locate the center that would conduct future manned space flight activities. Glennan had begun to question the wisdom of moving the the Space Task Group to Goddard after Mercury ended. The new center was becoming more and more occupied with unmanned space science programs, which Glennan did not want to see diluted and engulfed by manned space flight. On 1 September 1960, Robert C. Seamans, Jr., replaced Richard Horner as Associate Administrator. That same day, Seamans talked with Glennan about the future home of manned space flight. Goett and Gilruth had discussed the matter and had concluded that Gilruth should ask for separate center status for his group.⁴⁷



Caldwell C. Johnson's October 1960 sketch proposed the seating arrangement that was developed and adopted for the Apollo command module. The fourth figure illustrates the sleeping position.

CONCEPT TO CHALLENGE

At the end of the month, Glennan called for a special study of the relocation. A four-man team headed by Bruce Lundin began by collecting opinions from about 20 officials in the field and in Washington. Glennan's order basically restricted the candidate sites to an existing major NASA installation near which a proposed life sciences center might be built, insisted that Mercury not be disrupted by the move, and recognized that Apollo would use contractor participation to a far larger extent than Mercury. Glennan also decreed that Marshall, Lewis, and the High Speed Flight Station were not to be considered, which left only Ames and Langley as possible sites.

Lundin and his teammates Wesley Hjernevik, Ernest O. Pearson, Jr., and Addison M. Rothrock found their task difficult. Senior NASA officials did agree that manned space flight would soon need a center of its own. But where it should be and how it would be integrated into existing facilities was, it seemed, going to be a major issue. Lundin's group, after many administrative, political, and technical compromises, recommended rather weakly that manned space flight activity should probably be relocated in 1961 to Ames in California.⁴⁸

Gilruth, his technical assistant Paul E. Purser, and others leading the Space Task Group, who may not have been enthusiastic about the prospect of being uprooted from their Virginia homes, had little time to worry about a move. *Mercury-Atlas 1* had exploded in mid-air on 29 July, and morale among its managers was at its nadir. Unless these troubles could be overcome there might be little point in moving—there might not even be a Mercury program, much less a more advanced project. Gilruth was hard pressed to spare even enough of his experts to proceed with the feasibility studies for Apollo.⁴⁹

The three successful bidders began discussions with the Space Task Group on the technical aspects of their tasks almost immediately, with General Electric visiting its Langley-based monitors first. Donlan appointed three liaison engineers to act as single points of contact for the studies: Herbert G. Patterson for General Electric, John Lee for Martin, and William Petynia for Convair. Monthly meetings between these special monitors and the contractors kept Donlan and Piland informed of progress.⁵⁰

The industry conferences and the awarding of the feasibility contracts attracted the attention of the White House staff. George B. Kistiakowsky, Eisenhower's special assistant for science and technology, assigned Donald F. Hornig of the President's Science Advisory Committee (PSAC) to the chairmanship of a six-man ad hoc Panel on Man-in-Space.* This Group would investigate both NASA's activities thus far and its goals, missions, and costs in the foreseeable future. After several field trips, Hornig's

* Panel members were Malcolm H. Hebb, Lawrence A. Hyland, Donald P. Ling, Brockway McMillan, J. Martin Schwarzschild, and Douglas R. Lord (technical assistant).

CHARIOTS FOR APOLLO

panel reported: "As far as we can tell, the NASA program is well thought through, and we believe that the mission, schedules and cost are as realistic as possible at this time."

Obviously, the report continued, "any of the routes to land a man on the moon [will] require a development much more ambitious than the present Saturn program," calling not only for larger boosters but for lunar landing and takeoff stages as well. "Nevertheless . . . this new major step is implicit in the present Saturn program, for the first really big achievement of the man-in-space program would be the lunar landing."⁵¹

The cost of the moon landing would be determined to a great extent by the effort to develop, build, and qualify an extra-large and undefined Nova. Basing its estimates on Saturn costs to date, the PSAC panel placed this figure anywhere from \$25 to \$38 billion. Rendezvous schemes, as then envisioned, would afford little fiscal advantage: "Present indications suggest that alternative methods . . . of accomplishing the manned lunar landing mission could not be expected to alter substantially the over-all cost." In addition to its analysis of America's booster program in relation to a lunar landing objective, Hornig's panel summarized the worldwide significance of an expanded national space effort. "We have been plunged into a race for the conquest of outer space," the group said:

As a reason for this undertaking some look to the new and exciting scientific discoveries which are certain to be made. Others feel the challenge to transport man beyond frontiers he scarcely dared dream about until now. But at present the most impelling reason for our effort has been the international political situation which demands that we demonstrate our technological capabilities if we are to maintain our position of leadership. For all of these reasons we have embarked on a complex and costly adventure.⁵²

Early in 1960 Glennan had established a Space Exploration Program Council to oversee program planning and implementation. Near the end of the year, Seamans thought it wise to convene that body. Goett, von Braun, William H. Pickering, Ira H. Abbott, Silverstein, Major General Don R. Ostrander, and Albert F. Siefert met with Seamans on 30 September for a briefing by George Low on "Saturn Requirements for Project Apollo." Low posed five questions and defended his answers to them as proof of the realism of the proposed schedule for Apollo: (1) Will the spacecraft be ready in time to meet the Saturn schedule? (2) Will the spacecraft weight be within Saturn capabilities? (3) Are there any foreseeable technological roadblocks? (4) Will solar flare radiation prevent circumlunar flights by men? (5) What are the costs for this program?

To each of the five questions, Low made positive assertions of competence and capability. He argued that an Apollo circumlunar prototype

spacecraft could be ready in three to four years, a production vehicle in twice that time. Space Task Group weight estimates showed a reasonable margin between the weight of the spacecraft and the payload the C-2 Saturn could be expected to boost. No insurmountable technological obstacles were anticipated, Low said, not even reentry heating or solar flare radiation. Low concluded that the current cost level of \$100 million a year would eventually rise to approximately \$400 million annually. All of these considerations, in his opinion, argued for an immediate decision to go ahead. But the fact that this planning aimed at lunar circumnavigation rather than lunar landing seemed to be blocking approval of Apollo. NASA's top administrators appeared hesitant to fight for a mere flyby mission to the moon.⁵³

Low recognized this reluctance and on 17 October told Silverstein he was taking another tack:

It has become increasingly apparent that a preliminary program for manned lunar landings should be formulated. This is necessary . . . to provide a proper justification for Apollo, and to place Apollo schedules and technical plans on a firmer foundation.

To this end, said Low, he and Eldon Hall, Oran W. Nicks, and John Disher would try to establish ground rules for manned lunar landing missions, to determine reasonable spacecraft weights, to specify launch vehicle requirements, and to prepare an integrated development plan, including the spacecraft, lunar landing and takeoff system, and launch vehicles.⁵⁴

The Space Task Group, although still having difficulties with Mercury (in an attempted launch on 21 November, the first Mercury-Redstone had risen only a few centimeters off its pad), also moved to support a program that would be more than just a circumlunar flight. Gilruth had reorganized his people in September, setting up an Apollo Projects Office in Faget's Flight Systems Division. After getting the feasibility study contracts started, Faget, Piland (head of the new office), and J. Thomas Markley attended an Apollo-Saturn conference in Huntsville, at which they reported progress on the contracts. Later that afternoon, Faget and von Braun agreed to work together on a plan to place man *on* the moon and not just in orbit around it.⁵⁵

Gilruth assigned Markley as liaison with Marshall. Spending most of his time in Huntsville, Markley learned the opinions of many of von Braun's group on future vehicles and mission approaches and became well versed in their preference for rendezvous in earth orbit rather than direct flight, which would require vehicles much bigger than Saturn as then planned. In December, Markley reported to Donlan that Marshall was studying orbital assembly and refueling techniques and was planning to let contracts to industry for further studies on these subjects.⁵⁶

CHARIOTS FOR APOLLO

PORTENTS FOR APOLLO

During the latter part of the 1960 presidential campaign, Apollo (and even Mercury) faced a murky future. This period of doubt, caused by the imminent change in administrations, led Glennan to call a mid-October session at Williamsburg, Virginia, to wrestle with the question of future NASA programs. The attendees—including top management from Headquarters and all the centers—voiced varying opinions, but the need for a manned lunar landing program threaded throughout the discussions. Glennan observed that the decision on Apollo would have to wait until the new President took office, although he assumed there would be few changes, since space flight was surely a nonpartisan ambition. But the next month, November 1960, Glennan was still not sure that Apollo was ready to move beyond the study phase without more answers than all his committees and groups had yet produced. Before spending the \$15 billion he estimated Apollo would cost, Glennan wanted the reasons for going to the moon—international prestige or whatever they might be—laid out more clearly.

With the coming of the new year, then, there was a measure of uncertainty. Assuming that manned space flight would have some part in John F. Kennedy's "New Frontier," however, Glennan strengthened the chances for an Apollo program by announcing that the Space Task Group was a separate autonomous field element, responsible for all civilian manned space flight programs. Although the location of its permanent home was still unsettled—and Glennan favored Ames in California—Gilruth's position was affirmed. On the heels of this move, Glennan called the Space Exploration Program Council together again, to talk with many of those who had been at Williamsburg. He still warned that an Apollo hardware contract lacked presidential endorsement, but he also conceded that NASA seemed to be inevitably headed toward a lunar landing mission.⁵⁷

During the first week of January 1961, Glennan waited in vain for some member of the incoming administration to get in touch with him about the transition. Meanwhile, Dryden and Seamans discussed the coming congressional budget hearings for fiscal 1962.* At this time, they decided to formalize Low's committee as the "Manned Lunar Landing Task Group." The expanded team was to prepare a position paper to answer, in some depth, the questions, "What is NASA's Manned Lunar Landing Program? . . . How much is it going to cost to land a man on the moon and how long is it going to take?"⁵⁸

* Budget estimates drafted in September 1960 placed Apollo costs at \$100 000 for FY 1960 and \$1 000 000 for 1961; NASA intended to ask for \$35 500 000 for the program for FY 1962.

CONCEPT TO CHALLENGE

Low and his committee (still primarily a Headquarters group—Hall, Nicks, Alfred M. Mayo, and Pearson—but now including Faget and Koelle as spokesmen from the field centers for the spacecraft and launch vehicle) met on 9 January. Seamans outlined the group's task in detail. The members were to draft plans for a lunar program, describing both direct ascent and rendezvous, for use in budget presentations to Congress. They were to include cost and schedule estimates for both modes. Developing a plan for manned lunar landings was among NASA's major objectives, the group was reminded, even though the program was not yet approved.⁵⁹

During the next four weeks, the committee labored over "A Plan for Manned Lunar Landing" and submitted it on 7 February. Low told Seamans that the report "accurately represents, to the best of my knowledge, the views of the entire Group." No major technological breakthroughs, no crash programs, and no real physiological barriers were envisioned. The concurrent development of spacecraft and launch vehicle should lead, if financially supported, almost inevitably to a manned lunar landing in 1968 to 1970, they thought. Its costs ought to peak around 1966 and total about \$7 billion. The big Saturn and bigger Nova boosters would be built and tested anyway, the group reasoned, and a manned space station in earth orbit would probably be extant by then. Low conceived Apollo in two phases: first, extended earth-orbital missions; second, circumlunar, leading to lunar landing missions.

The Low Committee stated that lunar landings could be made by using either direct-ascent or earth-orbital-rendezvous modes. Launch vehicle development would determine how large a step NASA could take in space at any given time. Moon landings demanded launch vehicles that could lift from 27 200 to 36 300 kilograms into space fast enough to escape the earth's gravitational pull. (The C-2 Saturn in the agency's fiscal 1962 budget request would be able to boost no more than 7000–8000 kilograms to that velocity. It could thus send manned flights to the vicinity of the moon, but it could not land there and then return its cargo to the earth.) The committee cited two ways of getting this booster capability for manned landings, either refueling a number of C-2s in earth orbit or building a vehicle large enough to perform the mission directly from the ground. Although both appeared feasible, the earth-orbital-rendezvous scheme would probably be quicker. Accordingly, NASA must develop orbital operations techniques; refueling in orbit would probably be possible by 1967 or 1968.⁶⁰

And there the matter rested. Early 1961 was an unsettled period for NASA. With the country acquiring a new President and the agency a new Administrator, the prospect for moon flights was highly uncertain. But Kennedy was deeply interested in space. Before his inauguration, he had appointed an ad hoc committee, headed by Jerome B. Wiesner of the Massachusetts Institute of Technology, to review the entire missile and space effort. The Wiesner Committee's report, quite critical of the way

CHARIOTS FOR APOLLO

Mercury was being managed and of NASA's apparent bias in favor of manned space flight at the expense of the unmanned science programs, called for a stronger technical competency within NASA and a redefinition of goals.⁶¹ Because Wiesner had joined in the "missile gap" rhetoric during the November presidential campaign, his committee's report the following January was suspect in some quarters. Nevertheless, it spurred NASA's civil service workers to prove it wrong.

The Wiesner report also touched off a debate on the choice of a new leader for the space agency. Wiesner, like other scientifically oriented advisers within the administration, favored a proved and respected scientist-engineer. Shortly before his inauguration, however, Kennedy had delegated responsibility for space matters to Vice President-Elect Lyndon B. Johnson, long-time champion of America's space programs in Congress and architect of the 1958 legislation that created NASA. In contrast to Wiesner, Johnson wanted a hard-driving, politically experienced administrator to preside over the agency. When he was named to head the powerful National Aeronautics and Space Council, Johnson won.

Glennan's resignation from NASA was effective 20 January, but Kennedy did not announce his successor until the end of the month. In the interim, at the request of the White House staff, Dryden was Acting Administrator. On 30 January, the President ended a spate of speculation by naming James E. Webb as NASA's new head. Quickly confirmed by the Senate, Webb was sworn in on 15 February. Dryden, whose continued service the new Administrator solicited, remained as Deputy Administrator, personifying scientific interests within the agency.

Dramatic changes for NASA seemed likely. Webb was a man with a long and varied background in government, industry, and public service. During the Truman era he had first been Director of the Bureau of the Budget (1946-1949) and later Under Secretary of State (1949-1952). With forceful demeanor, grandiloquent style, and a genius for extemporization, Webb soon became a familiar figure on Capitol Hill as champion of the space program and defender of the agency—and its fiscal interests—before Congress.⁶²

Webb met with his key officials from Headquarters and the field centers at NASA's fifth semiannual retreat, in Luray, Virginia, 8-10 March 1961. He announced that Seamans would be the "operating vice president" of the agency and that the field centers would, in future, report directly to Seamans rather than to the major Headquarters staff offices, as in the past. There were hints of other significant changes that would be needed to manage a program the size of Apollo, once it was approved. Webb's ideas were not hatched overnight but were founded, in part at least, on documents passed on to him by Glennan. The principal contribution was a study led by Lawrence A. Kimpton, Chancellor of the University of Chicago. Contained in the "Kimpton Report" were recommendations that

the centers should report directly to the Associate Administrator, that formally established project offices should manage projects, and that NASA should rely more on contracting support. In 1961, many of these suggestions were implemented. Seamans' new assignment was the first step along that path.⁶³

Testimony before congressional committees began at the end of February. George Low described Apollo both as an earth-orbiting laboratory and as a program for circumlunar flight that could lead to a manned lunar landing. Abraham Hyatt outlined NASA's long-term objectives, with charts that showed large launch vehicle development as the pacing item.

Before Seamans and Low finished this round of testimony, a Russian test pilot named Yuri A. Gagarin circled the earth on 12 April in *Vostok I*. Congressional deliberations changed into direct demands to respond to the Russian challenge, just as they had in October 1957 after *Sputnik I*. Overton Brooks, chairman of the House Committee on Science and Astronautics, said bluntly on 14 April, "My objective, and this is speaking individually, is to beat the Russians." Seamans reminded the committee that Webb had told them only the day before that the cost of Apollo, without a crash program, would be between \$20 billion and \$40 billion over the next ten years. With an accelerated program, that figure could go even higher.⁶⁴

President Kennedy had begun strengthening the space program in late March. He sent Congress a revised fiscal 1962 budget for NASA, raising the agency's funding more than \$125 million over Eisenhower's recommended level of \$1.11 billion. Much of this increase was earmarked for the Saturn C-2 and the F-1 engine and was expected to speed up development of these important items significantly.*⁶⁵

Seamans suggested even greater increases than NASA actually received. Given the funding levels he proposed, manned circumlunar flight with the C-2 would be feasible in 1967 rather than 1969. The F-1 engine, essential to an even larger launch vehicle, was the key to manned landings. "*The*

* Kennedy and Webb held budgetary discussions on 22 March, in which they covered 11 actions NASA would have to take to accelerate the space program: (1) increase the number of Mercury flights to learn more about man's behavior in space; (2) initiate possible long-duration Mercury flights with intermediate launch vehicles; (3) accelerate exploration to provide data for manned flights; (4) speed up studies of manned reentries at lunar return velocities; (5) begin development of solid-propellant rockets for first or second stages of Nova; (6) start design work on clustered F-1 engines for Nova; (7) commence design engineering of Nova, using clustered F-1 engines for the first stage; (8) begin developing tankage and engines for Nova's second stage; (9) expedite supporting technology required for attainment of lunar goal; (10) start construction of launch pads and other facilities; and (11) provide additional vehicles and spacecraft to hasten the Tiros meteorological program. Budget Director David E. Bell later wrote the President that Webb and his associates had presented the case for an accelerated space program very well. But, he warned, the United States might be better advised to concern itself with "*men on earth*" rather than with putting "*men on the moon*."

CHARIOTS FOR APOLLO

first manned lunar landings," Seamans stressed, "depend upon this chemical engine as well as on the orbital and circumlunar programs and *can be achieved in 1970 rather than 1973.*" More money, he told Webb, "will increase the rate of closure on the USSR's lead in weight lifting capability and significantly advance our manned exploration of space beyond Project Mercury." Webb forwarded Seamans' memorandum to President Kennedy on 23 March 1961, in response to a request for information about NASA's plans.⁶⁶

While NASA's leaders appeared to have pushed Apollo closer to an approved program, activities in the field had also accelerated. The Technical Liaison Groups formed to evaluate the three industrial studies had grown to include, part-time, virtually every senior engineer in the Space Task Group, as well as representatives from other NASA centers. By mid-February, feverish preparations were being made by Donlan's office for separate midterm reviews of the Martin, General Electric, and Convair contracts. In March, the industrial teams came to Langley one by one and stood before a large audience who had come to hear what the contractors had to tell.

Each company followed roughly the same agenda: trajectory analysis; guidance and control; configuration and aerodynamics; heating; structures and materials; human factors; onboard propulsion; mechanical systems; and instrumentation and communications.

The NASA auditors commented on the presentations, each of which seemed a bit too general and lacking in the technical information the NASA planners wanted. Martin Company's team, for instance, led by E. E. Clark and Carlos de Moraes, was complimented for its briefing on mechanical systems but chided for neglecting structures and materials analyses related to Apollo design requirements. The General Electric group, headed by George R. Arthur and Ladislaus W. Warzecha, scored high on human factors but low in its discussions of mission abort studies, instrumentation, and communications.⁶⁷

Faget was especially irritated that none of the contractors had proposed modifying and expanding the blunt-body, Mercury-style spacecraft. Some theoreticians had predicted that the hot gas radiation heating caused by Apollo's greater reentry speeds would make this shape unacceptable, but experiments by Clarence Syvertson at the Ames Research Center indicated that these predictions would not materialize. In addition, Caldwell Johnson, Faget's chief design assistant, had recently finished a study on the advantages of the conical, blunt-body command module over the designs of any of the three contractors. Willard M. Taub, of the same office, later recalled that the contractors, after the midterm review, "had to jump in real fast and come in with a new vehicle based on the [Space Task Group] version." Conversely, Mel Barlow of Convair looked on the modified Mercury as only a slight technological advance. He said he was shocked to learn that NASA intended to keep that configuration.⁶⁸

CONCEPT TO CHALLENGE

While most of the Space Task Group labored under heavy operational pressures—the third Mercury-Atlas had failed almost as miserably as the first—the nine Technical Liaison Groups at Langley tried to clarify the engineering designs for a spacecraft that would circumnavigate, and perhaps land on, the moon. Although they acknowledged that Saturn C-2 (or its next larger version) should be capable of sending a large payload to that body, the questions of how large, by what route, and with what capacities were by no means settled or even well defined.⁶⁹

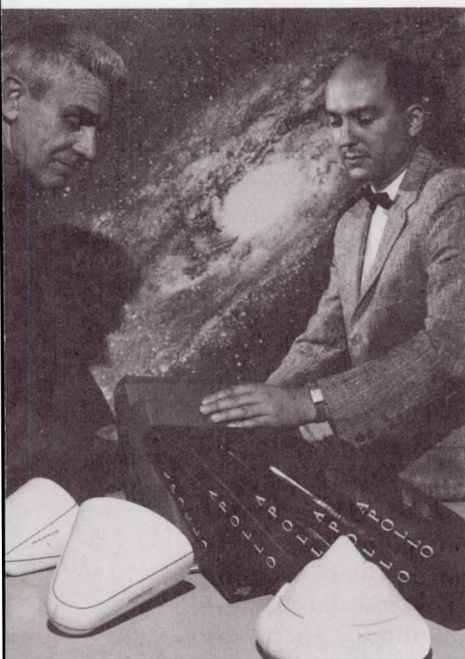
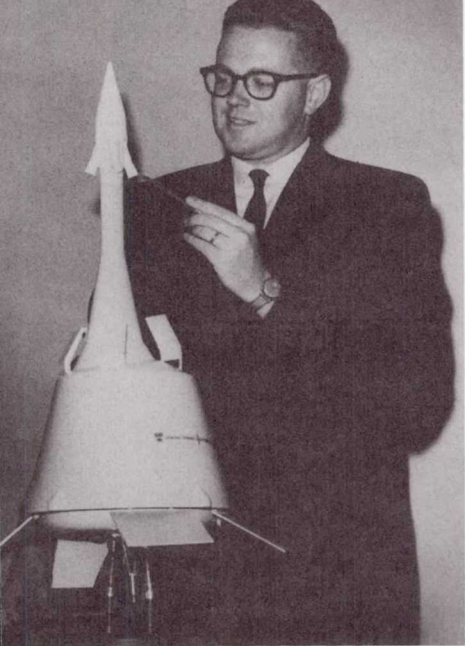
In early May of 1961, the first reports from the completed study contracts began arriving at the Space Task Group. All three contractors had spent considerably more than the \$250 000 NASA paid them for the work.

Convair/Astronautics' report depicted a three-module lunar-orbiting spacecraft. Command, mission, and propulsion modules were designed primarily for lunar orbit, with flexibility and growth potential built in for more advanced missions (such as a lunar landing) with the same basic vehicle design. A total Apollo cost of \$1.25 billion over about six years was estimated.

The San Diego-based company had selected a lifting-body concept, much like one conceived several years earlier by Alfred Eggers of Ames for the return vehicle. The command module, with an abort tower attached through launch, would nestle inside a large mission module. What Astronautics proposed was similar in its mode of operation to the command and service modules that ultimately evolved for Apollo. Convair/Astronautics envisioned mission planning as building progressively upon many earth-orbital flights before attempting circumlunar and then lunar-orbital missions. Earth landings would be by glidesail parachute near San Antonio, Texas. Elementary experiments that would evolve into rendezvous, docking, artificial gravity, maneuverable landing, and an eventual lunar landing were foreseen. The study cost the contractor about \$1 million, four times what NASA paid the company. The other two contractors spent even more of their own money.⁷⁰

General Electric's study cost twice as much as Convair's and featured a semiballistic blunt-body reentry vehicle. Had this configuration been selected, the payload sent to the moon would have resembled the nose cone flown on the early Saturn C-1. General Electric's design capitalized upon hardware already almost ready to fly, but it did offer one innovation—a cocoonlike wrapping for secondary-pressure protection in case of cabin leaks or meteoroid puncture. Although General Electric did not estimate the final costs in its summary, the company was confident of achieving circumlunar flight by the end of 1966 and lunar-orbital flight shortly thereafter.⁷¹

The Martin Company produced the most elaborate study of the three. Martin not only followed all the Space Task Group guidelines, but also went far beyond in systems analysis. Focusing on versatility, flexibility, safety margins, and growth, this was the only study that detailed the pro-



Using a model at upper left, William Rector of General Dynamics Corp. describes the design his company proposed for the Apollo lunar mission. NASA's second Administrator, James E. Webb (at center above), and George M. Low (right above) of NASA Headquarters receive a model of General Electric's proposed vehicle. At lower left, E. E. Clark and Carlos de Moraes of the Martin Company display three of a dozen command module configurations considered before the choice of the one to the right. De Moraes' hand rests on volumes containing about 9000 pages that the company submitted as its Apollo study.

gression of steps from lunar orbiting to lunar landing. Martin's spacecraft would have been similar to the Apollo spacecraft that ultimately emerged. Later, when the hardware contract proposals were evaluated, Martin scored first on configuration design.

Martin recommended a five-part spacecraft. The command module was a flat-bottomed cone with a rounded apex and a tower for a tractor-rocket

CONCEPT TO CHALLENGE

launch escape system. Behind the flat aft bulkhead were propulsion, equipment, and mission modules. Tradeoffs between weight and propulsion requirements led to the selection of a pressurized shell of semimonocoque aluminum alloy coated with a composite heatshield of superalloy plus charring ablator. Two crewmen would sit abreast, with the third behind, in couches that could rotate for reentry g-load protection and for getting in and out of the spacecraft. Flaps for limited maneuverability on reentry, a parachute landing system, and a jettisonable mission module that could also serve as a solar storm cellar, a laboratory, or even the descent stage for a lunar lander were also featured. Almost 300 persons in Martin spent the better part of the six months and about \$3 million on the data and designs for their recommendations.⁷²

NASA and its Space Task Group might have evaluated the contractor reports at a more measured pace in more normal times, but in April—the month before these reports came in—the pressures “to get America moving” toward the moon became intense.

THE CHALLENGE

In the aftermath of Gagarin's flight, President Kennedy asked Vice President Johnson to find a way to regain American technological prestige through space flight. NASA top management was in almost constant communication with the White House staff, Bureau of the Budget officials, and congressional leaders. Apollo was about to pass from planning to action. Less than a month and a half after the Russian feat, NASA's new manned space flight project was approved.

Now it is time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on earth.

... I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.

With these words, on 25 May 1961, President Kennedy proclaimed before Congress and the world that manned lunar landing belonged in the forefront of an expanded American space program.⁷³ And Congress obviously agreed with him. With almost no internal opposition, both the Senate and the House of Representatives responded to Kennedy's challenge by increasing funds for the agency that was to undertake this bold pro-

CHARIOTS FOR APOLLO

gram. At this juncture, the Americans had chalked up 15 minutes and 22 seconds of manned space flight experience. The Russians had clocked 108 minutes.

On 5 May 1961, NASA had launched *Freedom 7*, the first manned U.S. spacecraft. Pilot Alan Shepard became the forerunner of a new genre of American adventurer-hero, the astronaut.* Shepard's flight, a lob shot up over the Atlantic, was a far from spectacular demonstration of this country's spacefaring capabilities when compared to Gagarin's single orbit of the earth. But, as only the third flight of a Mercury-Redstone, it was a dangerous and daring feat.⁷⁴

NASA officials maintained that the agency was ready and eager to take on the lunar landing, even though it added enormously to the challenge of Apollo. Following the President's speech on 25 May, Webb, Dryden, and Seamans told newsmen that much of the additional funding Kennedy had requested would be spent on advanced launch vehicles, particularly Nova, the key to manned lunar landings. Nova was so crucial to Apollo, Webb declared, that the agency planned a parallel approach to the development of propellants for the big booster. NASA would continue its work on liquid propellants, while the Department of Defense would pursue solid-fueled-rocket development as an alternative for Nova's first stage. "As soon as the technical promise of each approach can be adequately assessed," he said, "one will be selected for final development and utilization in the manned space program."⁷⁵

Dryden expanded on Webb's statement. Asked if the agency considered orbital rendezvous a serious alternative to use of Nova, he replied, "We are still studying that, but we do not believe at this time that we could rely on [it]." He stressed that Kennedy's decision had forced NASA to begin work on Nova prematurely:

This illustrates the real nature of the decision. We could make some of these decisions better two years from now than we can now, if the program had gone along at the ordinary pace. But if we are going to accelerate this we have got to do some parallel approaches, at least for a time. The solid and the liquid propellant are going to be carried forward full steam. We have a certain amount of effort on rendezvous. If it looks like this presents any opportunity, we will certainly take advantage of it.⁷⁶

Both Dryden and Seamans freely admitted that NASA lacked the immediate scientific knowledge needed for lunar landings. Another use of the

* The first astronauts were military test pilots: from the Navy, Lieutenant Commanders Walter M. Schirra, Jr., and Alan B. Shepard, Jr., and Lieutenant M. Scott Carpenter; from the Air Force, Captains L. Gordon Cooper, Virgil I. Grissom, and Donald K. Slayton; and from the Marines, Lieutenant Colonel John H. Glenn, Jr.

CONCEPT TO CHALLENGE

additional funding would be to speed up research into the unknowns. Development of hardware—boosters, spacecraft, and equipment—must be built upon this scientific and technical foundation. At this juncture, nobody had any really firm idea about how NASA was going to implement Kennedy's decision. Techniques for leaving the earth and flying to the moon—even more, landing there and returning—were open to considerable debate and much speculation.

There was a vague feeling within the agency (though with several notable exceptions) that direct ascent would eventually be the answer, but no one had worked out the tradeoffs in much detail. Subsequently, as Apollo planning progressed, the question of how to fly to the moon and back loomed ever larger. In the end, the choice of mode was perhaps the single greatest technical decision of the entire Apollo program. The selection was inextricably linked to launch vehicles, spacecraft, facilities, cost, development schedules, and the future of America's posture in space. Ultimately, the mode question shaped the whole of Apollo. Many possible methods were carefully considered, and a Pandora's box of problems was opened. At the time, however, technical thinking had not matured to that degree. The United States was just on the threshold of manned space flight, and orbital flights around the earth were in themselves mind-boggling. A program to land men on the moon, 400 000 kilometers away, and bring them safely home was nearly too stupendous for serious contemplation.

One participant charged with transforming the concepts drafted by committees and study groups to hardware later described his reactions. Acutely aware that NASA's total manned space flight experience was limited to one ballistic flight and that he was being asked to commit men to a 14-day trip to the moon and back, Robert Gilruth said he was simply aghast.⁷⁷

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Project Planning and Contracting

May through December 1961

By the end of April 1961, NASA's three top executives—James Webb, Hugh Dryden, and Robert Seamans—knew that Apollo would soon become an approved project aimed at landing men on the moon. The agency's engineers had done some thinking but little planning for that particular step, which they viewed only as a possible objective for the 1970s. When President Kennedy's challenge in late May abruptly made moon landing a goal for the 1960s, adjustment within NASA to meet the new charge was not an easy task. Although transfers from other agencies and a few recently created offices had resulted in a relatively strong and versatile organization, in May 1961—and for months thereafter, for that matter—NASA was not really prepared to direct an Apollo program designed to fly its spacecraft around the moon. New and special facilities would be needed and the aerospace industry would have to be marshaled to develop vehicles not easily adapted to production lines, even though no one had yet decided just what Apollo's component parts should be or what they should look like.

Despite all the committee and task group work done since NASA opened for business, not one of the vehicles, from the ground up, was sufficiently defined for an industrial contractor to develop and build. Because of the time limitation imposed by Kennedy, Administrator Webb asked Associate Administrator Seamans to get the pieces of Apollo that were nearly defined under contract. With no appropriate project office to implement this order, ad hoc committees and task groups still had to do the work. For the remainder of 1961, until NASA could recruit enough

CHARIOTS FOR APOLLO

skilled people and organize them to carry out Apollo's mammoth assignment, Seamans would continue to operate in this fashion.

COMMITTEES AT WORK

To begin upgrading NASA's tentative planning from circumlunar flights to lunar landing missions, Seamans on 2 May set up an ad hoc group led by William A. Fleming of Headquarters.* The task was reminiscent of that given to George Low's committee earlier in the year, but the Fleming team was to place more emphasis on the landing stage than Low's group had. Since Seamans had given him little time to complete the study, Fleming settled on direct flight as the way to reach the moon. For the final approach to landing, his group concluded, a stage weighing 43 000 kilograms would be needed, with 85 percent of that being the fuel load.¹

Once Fleming had selected the direct route, Seamans realized that he needed more options, so he formed a second committee, headed by Bruce Lundin from the Lewis Research Center, to study the choices. The eight-man committee † looked at rendezvous, mostly earth-orbit rendezvous, in which two or more vehicles would link up near the home planet and journey to the moon as a unit, and lunar-orbit rendezvous, which required a single vehicle to fly to the moon, orbit that body while one of its sections landed on the surface and returned, and then travel back to earth.

Lundin's group believed that rendezvous offered two attractions: deciding on launch vehicle size—Nova or several proposed versions of an advanced Saturn—would not restrict future growth; and rendezvous would permit lunar landings to be made with smaller boosters, using rocket engines already under development. The Lundin team favored earth-orbit rendezvous, with two or three of the advanced Saturns. They considered it safer, although they conceded that lunar-orbit rendezvous would require less propellant and, in theory, could be done with a single Saturn C-3, one of the versions under consideration.²

NASA officials gathered on 10 June 1961 to hear what both Fleming and Lundin had to report. Although the audience asked a few questions after each presentation, it was obvious that neither committee had made real progress. They did root out some difficulties that lay ahead and present

* The Fleming Committee, composed of about 20 members from both Headquarters and the field centers, concluded that "it is not unreasonable to achieve the first attempt of a manned lunar landing in 1967 provided there is a truly determined National effort." Reaching this goal would depend on the development of an adequate launch vehicle.

† Lundin's team consisted of Alfred Eggers (Ames), Walter J. Downhower (Jet Propulsion Laboratory), Lieutenant Colonel George W. S. Johnson (Air Force), Laurence Loftin (Langley), Harry O. Ruppe (Marshall), and William J. D. Escher and Ralph May, secretaries (NASA Headquarters).

PROJECT PLANNING

some suggestions on how a lunar landing might be made. But, actually, little could be done at the time, and they knew it, since NASA did not know how much money Congress intended to appropriate.³

SPACECRAFT DEVELOPMENT DECISION

This sudden preoccupation in NASA's highest echelons with the mode of flying to the moon put the spacecraft development planners in a quandary. Space Task Group engineers had the contractors' feasibility study reports in hand and had used them and their own studies in drafting specifications for a spacecraft hardware contract. The major question was whether they would have to wait until all the pieces in the Apollo stack were defined before awarding the contract. Robert Gilruth went to Washington on 2 June to find out.

During a meeting with Abe Silverstein and his Space Flight Programs staff, a consensus developed on the six areas in which major contracts would be needed: (1) launch vehicles; (2) the spacecraft command center, which would double as the return vehicle; (3) the propulsion module, with extra duty as the lunar takeoff section; (4) the lunar landing stage, which would be both a braking rocket and a lunar launch pad; (5) the communications and tracking network; and (6) the earth launch facilities.⁴ To get these projects under way, Silverstein said, Seamans had approved letting the spacecraft development contract.⁵

Gilruth took this good news back to Virginia, but he and his men still had a question. What would industry be bidding on? The Space Task Group favored a modified Mercury capsule (a bell shape extended into a conical pyramid) and had worked on that design. Its chief competitor was a lifting-body design, with trims and flaps, championed by Alfred Eggers and his colleagues at the Ames Research Center.

Max Faget, leading spacecraft designer at the Space Task Group, later said that one of his major objectives was to make the Apollo command module big enough; they were just finding out all the problems caused by a too-small Mercury capsule. He set the diameter at the base of the Apollo craft at 4.3 meters, as opposed to Mercury's 1.8 meters. When Faget asked Wernher von Braun, at Marshall, to fly some models of the craft, there was a problem. Since early Saturn vehicles did not have a payload, Marshall had used spare Jupiter missile nose cones on the first test flights. Douglas Aircraft Company had resized the Saturn's S-IV stage to fit the Jupiter body, which was smaller than the Apollo command module. Marshall contended that enlarging the S-IV would cost millions of dollars, and Space Task Group did not argue the point. Until this time, the design concept for the Apollo heatshield had called for a sharp rim, as in Mercury, which increased the total drag and gave more lifting capability. Rather than de-

crease the interior volume, Faget's design team simply rounded the edge to match the S-IV.

The command module's rounded edges simplified another design decision. Faget wanted to use beryllium shingles on the afterbody, as he had in Mercury, to take care of reentry heating, but Langley engineers believed the spaceship would be traveling too fast for shingles to handle the heat. The design group decided to wrap an ablative heatshield around the whole command module. This wraparound shield had another advantage. One of the big questions about outer space was radiation exposure. James Van Allen, discoverer of the radiation belts surrounding the earth and named for him, had predicted exposure would be severe. Encapsulating the space vehicle with ablative material as an additional guard against radiation, even though it entailed a large weight penalty, was a big selling point for the heatshield.⁶

Space Task Group engineers were satisfied with their design, although none too sure that anyone else in NASA liked it. George Low, however, found merit in both the blunt- and lifting-body configurations and suggested to Silverstein that two prime spacecraft contractors be hired, each to work from a different set of specifications.⁷

Space Task Group engineers wanted no part of this dual approach. In early July, Caldwell Johnson summarized for Gilruth their reasons for insisting on the blunt-body shape. Johnson emphasized mainly the operational advantages and the experience gained from Mercury that would accrue to Apollo. He confined his discussion to the trip to the moon and back, making no mention of landing the craft on its surface.⁸ Those most concerned with the command module's basic configuration were still looking at the problems connected with circumlunar flight: a vehicle that could fly around the moon and back to earth, sustain three men for two weeks, and reenter the atmosphere at much higher speeds than from earth orbit.

Gilruth's Apollo planners pressed on, drawing up a hardware development contract for their chosen craft. This vehicle could be adapted for a lunar landing later, but that problem was shunted to the background for the time being. Jack Heberlig, a member of Faget's design team for the Mercury capsule, drafted the hardware guidelines for the Apollo command center spacecraft. While Heberlig's procurement plan was in final review at NASA Headquarters the first week in July, Robert Piland and John Disher were setting up a technical conference to apprise potential contractors of NASA's requirements. Invitations were sent to 1200 representatives from industry and 160 from government agencies.⁹

From 18 to 20 July 1961, more than 1000 persons (representing 300 companies, the White House staff, Congress, and other governmental departments) attended a NASA-Industry Apollo Technical Conference in Washington. The first day, NASA engineers talked about space vehicle design, mission profiles, and navigation, guidance, and control. On the

CHARIOTS FOR APOLLO

second day, the attendees heard papers on space environment, entry heating and thermal protection, and onboard systems. During these sessions, the Space Task Group speakers pushed their blunt-body shape.¹⁰

Gilruth's men never doubted that the keystone to Apollo was the spacecraft itself. As they waited for higher authority to act, they continued to plan with Marshall a series of tests using a blunt-body capsule.¹¹ By the end of July, Administrator Webb had approved the procurement plan, and Glenn Bailey, Gilruth's contracting officer, had mailed out the requests for proposals.¹²

While waiting for the companies to respond, NASA awarded its first hardware contract for Apollo. After spending six months on a feasibility study, the Instrumentation Laboratory of the Massachusetts Institute of Technology (MIT) received a contract on 9 August to develop the guidance and navigation system.¹³

ASTRONAVIGATION—THE FIRST APOLLO CONTRACT

The guidance and navigation (or "G&N") system was a central concern in spacecraft design. To get to the moon and back to earth was a monumental task. NASA and its predecessor, NACA, had little experience in this field; but neither had anyone else. When NASA opened for business in 1958, more work had been done in celestial mechanics for trips to Mars than to the moon. MIT, in fact, had an Air Force contract that included research on interplanetary guidance and navigation. Out of this came a relatively extensive study for an unmanned probe to pass by and photograph Mars. By the time it was finished, however, this kind of role in space belonged exclusively to NASA.

With the blessing of the Air Force, MIT engineers took the results of their study to NASA Headquarters on 15 September 1959. Their timing was bad; only two days earlier the Russians had crash-landed *Lunik II* on the moon (the first man-made object to reach that body) and had impressed the American space community by having built a launch vehicle powerful enough and a guidance system sophisticated enough to get it there. In this atmosphere, the MIT presentation netted only a small study contract. And when feasibility contracts for the Apollo spacecraft were awarded in November 1960, how to get the crew to the moon and back was still a question.¹⁴

Like other phases of Apollo, the G&N system drew on the past. The foundation had been laid by Kepler, Newton, and Laplace in theoretical celestial mechanics and had been advanced as a practical science by such devices as Foucault's gyroscope (an instrument Sperry later made almost synonymous with his name). These and other achievements in aerial navi-

PROJECT PLANNING

gation and space guidance and control were not sufficient for a trip to the moon, although some engineers in the Apollo program did use the early classics in estimating fuel and developing computerized trajectory equations.¹⁵

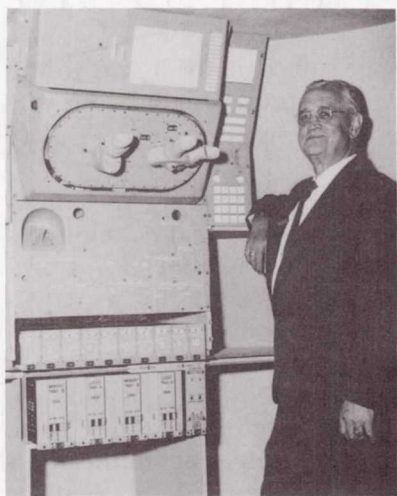
To a great extent, lunar navigation development relied on such newcomers in the field as computers and a worldwide tracking and communications network. By the 1960s, the electronic computer had become an integral tool of science, technology, and business. Without its capacities for memorizing, calculating, comparing, and displaying astronomical amounts of data, the lunar landing program would have been impossible. Worldwide tracking and communications networks evolved out of meteorology, astronomy, telemetry, missilery, and automatic spacecraft experience into manned space flight planning and operations. Most of the credit for telecommunications work at NASA operations belongs to the Goddard center in Greenbelt, Maryland. Myriads of data collected from unmanned satellites were processed daily in its computer banks and transmitted to such agencies as the Weather Bureau and the Geological Survey. Guidance and control technology shared the same evolutionary roots as tracking and communications, but it also drew on advances in avionics, gyroscopes, maritime and aerial navigation, antisubmarine and antiaircraft fire control systems, and cybernetics.¹⁶

MIT was the obvious place for NASA to look for help in Apollo's astronavigation problems. For many years, Charles Stark Draper, Director of MIT's Instrumentation Laboratory, had been recognized as the man most directly responsible for the application of automatic pilots and inertial guidance systems.¹⁷ Achievements in such second-generation intercontinental ballistic missiles as the Polaris made Draper's laboratory the logical sole-source choice for the Apollo system.

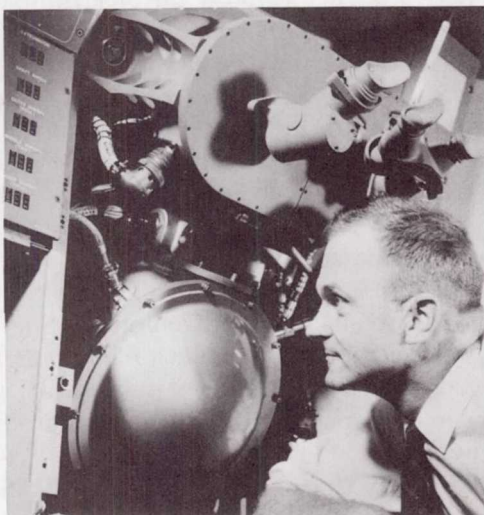
Draper appointed Milton B. Trageser as project manager and David G. Hoag as technical director. These new Apollo leaders consulted with guidance theoreticians at Ames Research Center,^{*18} before starting on the contract. Reassured by these talks and by the in-house MIT work of J. H. Lanning in 1958 on preliminary designs for a Mars mission and of J. S. Miller and Richard H. Battin in 1960 on studies of applied mathematics, Draper's laboratory was convinced that it had no near rivals in the field.¹⁹

When the MIT Instrumentation Laboratory signed a letter contract for Apollo on 10 August 1961, NASA officials assumed they had placed this complicated task in good hands. From the outset, there was a clear under-

* Before and during the Apollo feasibility studies, the Ames center had focused on guidance and navigation as the area where it could be most useful to Apollo. Stanley F. Schmidt had looked at midcourse guidance; Dean R. Chapman and Rodney Wingrove had concentrated on reentry guidance; and G. Allan Smith had worked on instrumentation for the astronauts' onboard operations.



Navigating to the moon: MIT Instrumentation Laboratory Director C. Stark Draper inspects a mockup of the Apollo guidance and control system in the September 1963 photo above. David G. Hoag, technical design director at the laboratory, examines the inertial measuring unit that would measure changes in Apollo spacecraft velocity when propulsion systems were fired.



standing that MIT would do only the technical design and prototype development; when the manufacturing phase commenced, industrial contractors would take over. NASA monitors anticipated some problems in employing separate firms to make the guidance, control, and navigation equipment—but that worry could wait. In the meantime, Draper's men were not completely sure that NASA people really understood the differences between the three terms.²⁰

"Guidance," to MIT, meant directing the movement of a craft with particular reference to a selected path or trajectory. "Navigation," in space as on the seas, referred to determining present position, as accurately as possible, in relation to a future destination. "Control," specifically in astronautics, was the directing of a craft's movements with relation to its attitude (yaw, pitch, and roll) or velocity (speed and direction, a vector quantity). MIT's expertise centered on the first two of these factors; NASA engineers (particularly those who had worked with earth-orbital flight) emphasized the first and third.²¹

PROJECT PLANNING

Still, NASA's Apollo engineers were encouraged by what they saw of the laboratory's work and were assured by MIT that getting to the moon and back was simpler than guiding an antiballistic missile or circumnavigating the earth under water in a nuclear submarine.*

NASA officials had some doubts. In June 1961, Dryden requested Draper to come to Washington to discuss G&N problems with Webb. Webb asked if MIT could really get a man to the moon and back safely. Draper replied that he would be willing to make the voyage himself, if Webb would guarantee the propulsion system. Over the next few months, Draper continued to hear mutterings of disbelief. To display his confidence in his team, he wrote Seamans, saying:

I would like to volunteer for service as a crew member on the Apollo mission to the moon. . . . We at the Instrumentation Laboratory are going full throttle on the Apollo guidance work, and I am sure that our endeavors will lead to success. . . . let me know what application blanks I should fill out. . . .²²

Draper's offer to serve as an astronaut caused a ripple of laughter throughout NASA Headquarters, but only for a moment. There were other problems to resolve. The basic rocket booster for the moon mission was still in question, and NASA's administrators were in the process of selecting a spacecraft manufacturer.

CONTRACTING FOR THE COMMAND MODULE

The attention devoted to guidance and navigation did not halt preparations for a contract on the command module. Data from the feasibility studies and from Space Task Group's in-house work were used to prepare a statement of work, detailing the contractor's responsibilities and the scope of his obligations in designing, building, and testing the spacecraft.²³

Project Apollo would have three phases: earth-orbital, circumlunar and lunar-orbital, and lunar landing. The prime spacecraft contractor would develop and build the command module, service propulsion module, adapter (to fit the spacecraft to a space laboratory for earth-orbital flights and to the lunar landing propulsion section for lunar missions), and ground support equipment. Although the prime spacecraft contractor would not build the lunar landing module, he would integrate that system into the com-

* On 10 May 1960, the U.S.S. *Triton* completed a 66 800-kilometer submerged cruise around the globe.

CHARIOTS FOR APOLLO

plete spacecraft stack and ensure compatibility of the spacecraft with the launch vehicle.²⁴

Just before leaving NASA early in 1961, Administrator Keith Glennan had revised the procedures for the establishment and operation of source evaluation boards. For any NASA contract expected to exceed \$1 million, all proposals would have to be evaluated by such a board; for any contract that might cost over \$5 million, all proposals would be judged by a special source evaluation board appointed by the Associate Administrator. The board's findings would then be passed to the Administrator himself for final selection. On 28 July 1961, Seamans approved the overall plan for Apollo spacecraft procurement, appointed the source evaluation board members, and delegated authority for establishing assessment teams to assist the board. Then the Space Task Group issued its request for proposal to 14 aerospace companies.*²⁵

Working arrangements for the development contract followed very closely those evolved for the feasibility studies. The deadline for the submission of proposals was set for 9 October 1961, giving prospective bidders more than ten weeks to work out their proposals. A conference was held on 14 August so NASA could explain the guidelines for the contract in detail. Almost 400 questions were asked at the meeting and answered; the answers were recorded and distributed. Seamans then appointed an 11-man Source Evaluation Board, headed by Faget and including one nonvoting member from Headquarters (James T. Koppenhaver, a reliability expert). The board consisted of six voting members from the Space Task Group (Robert Piland, Wesley Hjernevik, Kenneth S. Kleinknecht, Charles W. Mathews, James A. Chamberlin, and Dave W. Lang), one from Marshall (Oswald H. Lange), and two from Headquarters (George Low and Albert A. Clagett). Faget's board directed the technical assessment teams and a business subcommittee to work out and submit a numerical scoring system for comparative analyses of the proposals.²⁶

On 9 October 1961, five hopeful giants† of the aerospace industry brought their proposals to the Chamberlain Hotel, Old Point Comfort, Virginia. During the first two days of a three-day meeting, these documents were distributed among the members of the NASA assessment teams. The massive technical proposals, separated from those on business management and cost, were scrutinized and evaluated by more than a hundred specialists.

* The 14 firms were Boeing, Chance Vought, Douglas, Astronautics Division of General Dynamics, General Electric, Goodyear Aircraft, Grumman, Lockheed Missiles & Space Company, Martin, McDonnell, North American, Radio Corporation of America, Republic Aviation, and Space Technology Laboratories (STL).

† General Dynamics/Astronautics with Avco; General Electric, with Douglas, Grumman, and STL; McDonnell, with Lockheed Aircraft, Hughes Aircraft, and Chance Vought; Martin; and North American.

PROJECT PLANNING

Each group of bidders was then called in on the third day to make an oral presentation and answer questions. Gilruth persistently asked the proposal leaders, "What single problem do your people identify as *the* most difficult task in getting man to the moon?"²⁷ The industrialists' answers to this question generally stressed the balance between performance, cost, and schedule controls for so complex an undertaking.

Several weeks of intensive study followed, as the assessment teams made their rankings of the proposals. Submitted on 24 November 1961, the report of the Source Evaluation Board summarized the scoring by the assessors and evaluators:

SEB Ratings of Apollo Spacecraft Proposals by Major Area

	Technical Approach (30%)	Technical Qualification (30%)	Business (40%)
Martin Co.	5.58 (out of 10)	6.63	8.09
General Dynamics/Astronautics	5.27	5.35	8.52
North American Aviation	5.09	6.66	7.59
General Electric Co.	5.16	5.60	7.99
McDonnell Aircraft Corp.	5.53	5.67	7.62

This step led to a summary rating, with Martin scoring 6.9, General Dynamics tied with North American at 6.6, and General Electric matched with McDonnell at 6.4 for final grades. The board was unequivocal in its final recommendation:

The Martin Company is considered the outstanding source for the Apollo prime contractor. Martin not only rated first in Technical Approach, a very close second in Technical Qualification, and second in Business Management, but also stood up well under further scrutiny of the board.

If Martin were not selected, however, the board suggested North American as the most desirable alternative.

North American Aviation [NAA] . . . rated highest of all proposers in the major area of Technical Qualifications. North American's pertinent experience consisting of the X-15, Navajo, and Hound Dog coupled with an outstanding performance in the development of manned aircraft (F-100 and F-86) resulted in it[s] being the highest rated in this area. The lead personnel proposed showed a strong background in development projects and were judged to be the best of any proposed. Like Martin, NAA proposed a project managed by a single prime contractor with subsystems obtained by subcontracting, which also had the good features described for the Martin proposal. Their project organization, however, did not

CHARIOTS FOR APOLLO

enjoy quite as strong a position within the corporate structure as Martin's did. The high Technical Qualification rating resulting from these features of the proposal was therefore high enough to give North American a rating of second in the total Technical Evaluation although its detailed Technical Approach was assessed as the weakest submitted. This relative weakness might be attributed to the advantage of the McDonnell Aircraft Corporation's Mercury experience, and the other three proposers' experience on the Apollo study contracts. The Source Evaluation Board is convinced that NAA is well qualified to carry out the assignment of Apollo prime contractor and that the shortcomings in its proposal could be rectified through further design effort on their part. North American submitted a low cost estimate which, however, contained a number of discrepancies. North American's cost history was evaluated as the best.²⁸

Word leaked out prematurely to Martin that it had scored highest in the evaluations. After two years of planning and five weeks of waiting, the Martin employees were informed over the public address system on 27 November 1961 that they had won the contest to build the moonship. The next day they learned the truth.²⁹

North American won the spacecraft development sweepstakes. Webb, Dryden, and Seamans apparently chose the company with the longest record of close association with NACA-NASA and the most straightforward advance into space flight. The decision would have to be defended before Congress and would be the cause of some anguish later.³⁰ When it was announced on 28 November, shouts of joy rang through the plant at Downey, California, as John W. Paup broke the news over the "squawk box."³¹

During December 1961, Space Task Group (renamed Manned Spacecraft Center on 1 November) and North American program directors and engineers met in Williamsburg, Virginia, to lay the technical groundwork for the spacecraft development program and begin contract negotiations.³² The spacecraft portion of Apollo had entered the hardware phase, although the launch vehicle (or vehicles) and the lunar lander had not.

INFLUENCES ON BOOSTER DETERMINATION

Concurrently with the agreement that Gilruth should get started on the spacecraft development contract, Associate Administrator Seamans realized that it was time to decide what the rest of the Apollo stack should comprise. The method chosen for the lunar trip—rendezvous or direct ascent—would affect Apollo's costs and schedules, as well as the launch vehicle configuration.

A launch vehicle to support the moon landing was a big question mark when the President issued his challenge in May 1961. The Space Task Group wanted to get its opinions on the record—not really sure how big

PROJECT PLANNING

a vehicle would be needed but rather hoping that NASA would develop the Nova. Marshall wanted to build a big liquid-fueled rocket but was a little chary about tackling a vehicle the size of Nova. One aspect that caused the Huntsville center to hold back was the high cost projected for the F-1 engines. When he learned of Huntsville's misgivings, Max Faget suggested that solid-fueled rockets be used for the first stage.

Faget thought the first stage should consist of four solid-fueled engines, 6.6 meters in diameter; these could certainly accomplish whatever mission was required of either the Saturn or Nova, whichever was chosen, at a reasonable cost. It made good sense, he said, to use cheap solid fuels for expendable rockets and more expensive liquid fuels for reusable engines. "We called the individual solid rocket 'the Tiger' because we figured it would be a noisy animal and would roar like a tiger," Faget remembered. But he and his group could not sell their idea. Liquids were preferred by both Headquarters and Marshall, who insisted that the solids were too heavy to move from the casting pit to the launch pad. They also argued, he said, that solids had poor burning characteristics and were unstable. So the launch vehicle question dragged on, although pressure to make some sort of decision did not lessen.³³

After the Fleming and Lundin Committee study reports had been distributed, Seamans met with several Headquarters program directors to discuss whether the advanced Saturn, called the C-3, recommended by Lundin's team could make the voyage to the moon if the earth-orbital rendezvous approach were chosen. Silverstein warned that the vehicle's upper stages were simply not well enough defined as yet.³⁴ Seamans agreed. On 20 June 1961, he asked Colonel Donald H. Heaton to head a task force* to study the C-3 and its possible employment in a manned lunar landing mission using rendezvous techniques.³⁵

Heaton's group followed Fleming's lead in narrowing the scope of its investigations to a single mode—in this case, earth-orbital rendezvous—as the way to go. Most of the members agreed that this mode offered the earliest chance for a landing. Either the C-3 or its next larger version, a C-4, could be used. But the team urged that NASA begin work on the C-4, because it "should offer a higher probability of an earlier successful manned lunar landing than the C-3." Moreover, a rendezvous capability would enable the C-4 to cope with future payload increases that the direct-ascent, Nova-class booster, with its fixed thrust, would be unable to handle.³⁶

* Heaton's committee was made up of Commander L. E. Baird (Navy); Richard B. Canright, Norman Rafel, Joseph E. McGolrick, L. H. Glassman, John L. Hammersmith, Robert D. Briskman, James Nolan, Warren North, and William H. Woodward (NASA Headquarters); Wilson B. Schramm, R. Voss, Paul J. DeFries, Heinz Koelle, and Harry Ruppe (Marshall); William H. Phillips and John Houbolt (Langley); Hubert M. Drake (Flight Research Center); and J. Yolles (Air Force Systems Command).

CHARIOTS FOR APOLLO

On 22 June 1961, Webb and Dryden met with several of their top lieutenants to see what useful items could be gleaned from the reports of all these committees for charting Apollo's strategy. Abraham Hyatt, the new chief of Plans and Programs, criticized any plan that required development of two launch vehicles, one for circumlunar missions and another for direct flight. Hyatt suggested that NASA either build a huge launch vehicle with as many as eight F-1 engines in the first stage for both circumlunar flight and lunar landing or cluster half that number of these engines in a somewhat smaller vehicle and use rendezvous techniques.³⁷

This meeting did produce several significant program decisions. Most important was the order for Marshall to stop work on the C-2, begin preliminary design on the C-3, and continue studies of a much larger vehicle for lunar landing missions. (By this time, what constituted a Saturn, in any of its versions, or a Nova was becoming hard to understand. For some clarification of the confusion, see the accompanying list.)³⁸

Early in July, Seamans appointed a Lunar Landing Steering Committee,* with himself as chairman, to meet every Monday afternoon until an impending Headquarters reorganization was completed. During its three meetings in July, the committee considered the facilities and organization needed to manage Apollo and then turned its attention to launch vehicles. But nothing tangible emerged from these discussions, either, certainly no hardbound decision on a launch vehicle for Apollo.³⁹

HELP FROM THE DEPARTMENT OF DEFENSE

Top-flight officials both in NASA and the Kennedy administration, when they recommended a moon landing program as the focus of America's space effort, saw Apollo as a central element of a broad national space program. The United States needed not only to develop more powerful boosters, to match Russia's, but to plan that development with a minimum of unnecessary duplication among agencies.⁴⁰

Early in July 1961, Seamans and John H. Rubel, Assistant Secretary of Defense and Deputy Director of Defense Research and Engineering, agreed on the need for joint NASA-Defense planning. Seamans informed Webb that the two agencies would try to determine what boosters would best meet the requirements of both the Department of Defense (DoD) and

* The steering committee attendance was flexible; the only members who met regularly were Seamans, Don Ostrander, Ray Romatowski, and Fleming (committee secretary). Less frequent attendees were Silverstein, Ira Abbott, Hyatt, DeMarquis D. Wyatt, Nicholas E. Golovin, Alfred Mayo, G. Dale Smith, John D. Young, Charles H. Roadman, Low, Milton W. Rosen, and Wesley Hjernevik (all of Headquarters); Eberhard F. M. Rees and Hans H. Maus (of Marshall); and Gilruth (STG).

Apollo Launch Vehicles

*Saturn C-1 (renamed Saturn I).** Configuration: S-I booster (eight H-1 engines, clustered, with 6.7-million-newton [1.5-million-pound] combined thrust), S-IV second stage (four engines using liquid-hydrogen and liquid-oxygen propellants, with 355 800-newton [80 000-pound] total thrust), and S-V third stage (two engines like those in the S-IV stage, with 177 900-newton [40 000-pound] total). In March 1961, NASA approved a change in the S-IV stage to six engines that, though less powerful individually, delivered 400 300 newtons (90 000-pound thrust) collectively. On 1 June 1961, the S-V was dropped from the configuration.

*Saturn C-1B (renamed Saturn IB).** Configuration: S-IB booster (eight clustered uprated H-1 engines with 7.1-million-newton [1.6-million-pound] total thrust) and S-IVB second stage (one J-2 engine with 889 600 newtons [200 000 pounds]). On 11 July 1962, NASA announced that the C-1B would launch unmanned and manned Apollo spacecraft into earth orbit.

Saturn C-2. Four-stage configuration: S-I booster, S-II second stage (not defined), S-IV third stage, and S-V fourth stage.

Three-stage configuration: S-I booster, S-II second stage (not defined), and S-IV third stage. Plans for the C-2 were canceled in June 1961 in favor of the proposed C-3.

Saturn C-3. Configuration: booster stage (two F-1 engines with a combined thrust of 13.3 million newtons [3 million pounds]), second stage (four J-2 engines with a 3.6-million-newton total [800 000 pounds]), and S-IV third stage. Plans for the C-3 were canceled for a more powerful launch vehicle.

Saturn C-4. Configuration: booster stage (four clustered F-1 engines with 26.7-million-newton [6-million-pound] combined thrust) and a second stage (four J-2 engines with combined thrust of 3.6 million newtons [800 000 pounds]). The C-4 was briefly considered but rejected for the C-5.

*Saturn C-5 (renamed Saturn V).** Configuration: S-IC booster (five F-1 engines, clustered, with total thrust of 33.4 million newtons [7.5 million pounds]), S-II second stage (five J-2 engines with total of 4.5 million newtons [1 million pounds]), and S-IVB third stage.

Saturn C-8. Configuration: First stage (eight F-1 engines, clustered, with a combined 53.4 million newtons [12-million-pound thrust]), second stage (eight J-2 engines with total of 7.1 million newtons [1.6 million pounds]), and third stage (one J-2 engine with 889 600 newtons [200 000 pounds]).

Nova. Configuration: several proposed, all using F-1 engines in the first stage. One typical configuration consisted of a first stage (eight F-1 engines, clustered, with 53.4-million-newton [12-million-pound] total thrust), a second stage (four liquid-hydrogen M-1 engines with combined thrust of 21.4 million newtons [4.8 million pounds]), and a third stage (one J-2 engine with 889 600 newtons [200 000 pounds]). Nuclear upper stages were also proposed.

* Only the three vehicles indicated by an asterisk were actually developed and flown in the Apollo program.

CHARIOTS FOR APOLLO

NASA. The civilian agency's central concern, of course, was a launch vehicle for Apollo.⁴¹

With the approval of both Defense Secretary Robert S. McNamara and Administrator Webb,⁴² Rubel and Seamans set up a DoD-NASA Large Launch Vehicle Planning Group on 20 July. Although Nicholas Golovin, an applied mathematician and Seamans' Technical Assistant, shared the chair with Lawrence Kavanau, a missile expert from the Defense Department, the group soon became known as the Golovin Committee.*

This committee, like all the others, found that, for Apollo, vehicle selection and mode were inseparable. At first the planners considered only direct ascent and earth-orbital rendezvous, but they soon broadened their study to include other kinds of rendezvous.⁴³ When it became apparent that the committee intended to delve deeply into the mode issue, Harvey Hall (of NASA's Office of Launch Vehicle Programs) asked that Marshall, Langley, and the Jet Propulsion Laboratory each study one particular kind of rendezvous—earth-orbit, lunar-orbit, or lunar-surface—and prepare a report for the Golovin group. Hall's own office would study direct ascent.⁴⁴

Worried that this latest in the series of Headquarters committees established to select a launch vehicle for Apollo would also get bogged down in the mode issue, Gilruth wrote Golovin about the degree to which rendezvous had pervaded recent thinking. "I feel that it is highly desirable," he said, "to develop a launch vehicle with sufficient performance and reliability to carry out the lunar landing mission using the direct approach. . . . I am concerned that rendezvous schemes may be used as a crutch to achieve early planned dates for launch vehicle availability, and to avoid the difficulty of developing a reliable NOVA class launch vehicle."⁴⁵

Just as Gilruth had feared, Golovin's group did get mired in the mode issue, leaving the choice of an Apollo launch vehicle still unsettled. On 18 September, one committee member said the group preferred rendezvous rather than direct flight, because smaller vehicles would be available earlier than the large boosters. Preliminary conclusions indicated that the manned lunar landing might be made with the C-4 more safely than with the Nova. Moreover, the C-4 would be more useful to other NASA and Defense Department long-range needs.⁴⁶

* The Golovin Committee originally comprised 14 member and alternate positions, equally divided between DoD and NASA. By the end of the study, these had expanded to 18 and included personnel from Aerospace Corp. (acting as advisers to DoD). The final roster listed Golovin (chairman), Eldon Hall, Harvey Hall, Milton W. Rosen, Kurt R. Stehling, and William W. Wolman (NASA Headquarters); Laurence Kavanau (cochairman and Director of Office of Defense); Warren Amster and Edward J. Barlow (Aerospace); Aleck C. Bond (Space Task Group); Seymour C. Himmel (Lewis); Wilson B. Schramm and Francis L. Williams (Marshall); Colonel Mathew R. Collins (Army); Rear Admiral Levering Smith and Captain Lewis J. Stecher, Jr. (Navy); and Colonel Otto J. Glasser, Lieutenant Colonel David L. Carter, and Heinrich J. Weigand (Air Force). James F. Chalmers, Aerospace, was secretary.

PROJECT PLANNING

Golovin himself disagreed with the majority of his group, insisting that direct flight was the safest and best way to go. He and those of his team who shared his belief talked to Seamans and Rubel about solid-fueled versus liquid-fueled rocket engines for Nova, the concept of modules (or building blocks) to achieve a variety of launch vehicles, and an S-IVB stage, which could be powered by a single J-2 engine.

Seamans, observing that some kind of advanced Saturn seemed to be inevitable, asked Golovin how many F-1 engines should be in the vehicle's first stage. Golovin replied, "Four—anything [less] is a waste of time." Golovin also recommended that the advanced Saturn be engineered so it could become most of the Nova as well.⁴⁷

At the committee's general sessions on 23 and 24 October, debates grew hotter over solid- versus liquid-fueled engines for the Nova, the size of the huge booster, and the merits of five rather than four F-1 engines in the advanced Saturn's first stage. Heinrich Weigand and Matthew Collins objected strongly to any assumption that rendezvous in space would be easy. Weigand contended that his fellow committeemen were underestimating the difficulty of rendezvous and docking. He wanted a Nova with large solid-fueled rocket engines in its first stage. Collins also urged that direct ascent be given first priority.

Cochairman Kavanau warned that "lunar orbit rendezvous or direct is the only way to beat the Russians," adding that he believed the C-4 could do the job either way. Golovin countered that "competition with the Russians is a permanent thing." He insisted that both orbital operations and the development of large boosters would have to be studied for at least two years before any mode choice was possible.

After listening to the cochairmen express opposing views, Collins asked bluntly: "Are we going to recommend rendezvous or direct?" Reminded that this was not in their charter—they were supposed to be selecting a launch vehicle to support either rendezvous or direct flight—the group returned to the arguments over four versus five engines for the advanced Saturn's first stage and the Nova's configuration.⁴⁸

And there the issues lay. Once again nothing was settled, although the October sessions wound up the Golovin Committee meetings. The group's greatest value had been as a forum for discussions on vehicle models and possible configurations for Apollo. The committee's conclusions—or lack of them—reflected compromises and conflicting opinions. After three months' intensive study of numerous vehicle combinations and mission approaches, the question of a launch vehicle for Apollo was still unresolved.⁴⁹

On 16 November, Webb and McNamara reviewed the areas explored by Golovin's group and made several policy decisions. They agreed to halt the development of large solid rocket motors (6.1 meters or larger) as a backup for the F-1 liquid engine, although the Defense Department would "continue to carry out advanced state-of-the-art technical development in

CHARIOTS FOR APOLLO

the solid field." And they decided that the Saturn C-4 should be developed for the rendezvous approach to Apollo.⁵⁰

CHOICE OF FACILITIES

While the launch vehicle was being debated by committee after committee, Administrator Webb was making decisions on the numbers, kinds, and locations of the special facilities and real estate needed to launch men to the moon. Within five months—from June to October 1961—four new installations, all in the Gulf Coast states, had been added to NASA's far-flung domain.⁵¹

Although size of the launch vehicle for Apollo had still not been decided, everybody agreed it would be big, too big for the launch pads at the Cape. The first thing NASA needed was a more adequate spaceport. To fabricate and assemble the lower stages of whatever rocket was selected would require a huge manufacturing plant, preferably one already in existence. The agency would need additional land, separate from the spaceport but near the factory, to static-test the booster. Safety and noise considerations demanded an immense area that could contain not only the test stands but a buffer zone as well. And, finally, if Gilruth's team was to manage all manned space flight projects, as it had been assigned to do in January 1961, there would have to be a site for spacecraft engineering and development facilities.

The monstrous size envisioned for the launch vehicle and the need for these installations to be accessible to each other brought an additional factor into play. Since the booster would have to be transported by water, the agency would need ice-free waterways for year-round operations. NASA planners looked, logically, at the Gulf Coast, which had a temperate climate and an intercoastal waterway system. Two of the five states, Florida and Alabama, already had Apollo-oriented centers, which led to the reasoning that the new facilities should be situated nearby.⁵²

Kurt H. Debus, as leader of NASA's launch operations (first for Wernher von Braun, then for all of the agency's flights from Cape Canaveral, Florida), had long dreamed of building a spaceport. In July 1961, he and Major General Leighton I. Davis, Commander of the Air Force Missile Test Center at the Cape, endorsed a report on eight proposed sites. Led by Major Rocco A. Petrone, Colonel Leonard Shapiro, and Colonel Asa B. Gibbs, the Debus-Davis study group evaluated Cape Canaveral (offshore); Cape Canaveral (onshore—Merritt Island); Mayaguana (in the Bahama Islands); Cumberland Island (off the southeastern coast of Georgia); Brownsville, Texas; Christmas Island; Hawaii; and White Sands, New Mexico. Only White Sands and Merritt Island were economically competitive, flexible, and safe enough to be considered further.⁵³ On 24 August, NASA

PROJECT PLANNING

announced that it had chosen Merritt Island and that it would buy 323 square kilometers of land for the new NASA launch center.

Debus had well-thought-out ideas for mobile launch operations facilities: the big boosters would be assembled (stacked vertically) and checked out under protective cover and then moved to the launch pad. He drew up plans for personnel buildup, construction contracts, and administrative autonomy. On 7 March 1962, when Marshall's Launch Operations Directorate became NASA's Launch Operations Center, Debus was ready. (After the assassination of the President in November 1963, the new installation would be renamed the John F. Kennedy Space Center.)⁵⁴

In Huntsville, von Braun viewed the facilities for an accelerated booster development program in a different light. His 6000 employees were housed in part of the Army's Redstone Arsenal, on the Tennessee River. Although it was adequate for engineering development and static-testing of smaller rockets, the Marshall center could not handle the immense vehicles planned for the lunar voyage. Von Braun would need land and facilities elsewhere, but with access to the navigable waters of the Tennessee Valley Authority. A survey of government-owned war surplus plants revealed one near St. Louis and another (named Michoud) near New Orleans that were suitable for building the huge boosters. But the Mississippi River around St. Louis often froze over during the winter months. So Michoud, with a mammoth building that contained 0.17 square kilometers under one roof as part of a 3.5-square-kilometer complex along the water's edge, was selected on 7 September 1961.* Designed as a shipyard, it had become a cargo aircraft factory in 1943 and a tank engine plant during the Korean conflict. Here the Chrysler Corporation and The Boeing Company would construct the first stages of the Saturn C-1 and, later, of the C-3, C-4, or C-5 (or whatever model was chosen).⁵⁵

Influencing the Michoud decision was the need for a test operations area nearby where acoustics could be managed and controlled, as well as logistics. Von Braun's team had always worried about the noise and vibration generated during static-testing (and so had the citizens of Huntsville). As boosters became larger, they became louder, and their low-frequency resonances threatened all kinds of structural damage. Using statistics gathered from Saturn C-1 decibel and vibration levels, acoustics experts estimated that the advanced Saturn would require a much larger buffer zone.

* Although the Saturn versus Nova debates continued, the selection of Michoud ended all chances of clustering eight F-1 engines in the first stage—unless the plant roof were raised. The fact that only four or five barrels could be put together did not worry Marshall, as this number would be more than enough to support assembly in earth orbit, that center's favored mode. Proponents of direct flight had essentially lost their vehicle; but they continued to argue for another year, anyway.

CHARIOTS FOR APOLLO

Marshall occupied only about 65 square kilometers of the more than 161-square-kilometer Redstone Arsenal, and the Army needed the rest of the land for its own rocket development and test programs. But even the whole expanse would not have been large enough for the superbooster. What NASA required was about 400 square kilometers. So large a purchase could be touchy if not properly handled. NASA officials worked through Congress, while site survey teams operated through the executive branch and administrative channels on a gargantuan land deal not far from Michoud. Lieutenant Colonel S. F. Berry, detailed to NASA's Office of Launch Vehicle Programs from the Army Corps of Engineers, helped the selection committee narrow the test site choices.⁵⁶

On 25 October 1961, NASA announced that it would purchase outright 54 square kilometers in southwest Mississippi and obtain easement rights over another 518 square kilometers in Mississippi and Louisiana for the big booster static-test site. Simultaneously, the Justice Department filed suits of condemnation, under the law of eminent domain, in the United States District Courts in both states. The area, largely flat pine forest, was on the Pearl River, only 56 kilometers northeast of Michoud. Well suited to NASA's needs because of its deep-water access and low-density population, the Pearl River site was bought for about \$18 million. While engineers at Marshall drew up specifications for static-test stands, canals, and storage areas, nearly 100 families, including the whole community of Gainsville, Mississippi, had to sell out and relocate. There were few complaints, as most of the residents were pleased at the prospect of new economic opportunities.⁵⁷

Meanwhile, Ralph E. Ulmer and Paul G. Dembling, facilities and legal experts at NASA Headquarters, were saddled with most of the worries connected with the whirlwind activities of site scouting and selection for the manned space flight center. For example, Ames Research Center Associate Director John F. Parsons, who led the search for the spacecraft development center, reported to Dembling and Ulmer, and no one else, on the whereabouts of his team and its need for advice and support. Webb, Dryden, and Seamans referred all inquiries to Dembling, in an effort to avoid undue pressures from persons and groups trying to advance local prospects.⁵⁸

On 13 and 14 September 1961, Webb and Dryden reviewed all the factors in selecting the site for manned space flight activities and decided to move that NASA function to Houston.* NASA announced the decision on 19 September 1961. Gilruth and his Space Task Group would soon have a home of their own to manage, a place in which to develop the payloads for future rockets. Webb called it "the command center for the manned lunar landing and follow-on manned space flight missions," intimating that

* For details of procedures and the criteria on which the decision was based, see Appendix A.

PROJECT PLANNING

an integrated mission control center would also be located in the Houston area.

Most Space Task Group “Virginians”—both native and otherwise—were not very happy over the prospect of a transfer to Texas. But NASA’s opportunity to accept a politically arranged gift of four square kilometers of saltgrass pastureland was too good to refuse.* Of course, there were the usual charges of undue political influence, largely from the areas that had been turned down. The fact that there were Texans in powerful political positions—Vice President Johnson and Congressman Albert W. Thomas (chairman of the House Independent Offices Appropriations Committee)—provided much of the ammunition for a brief barrage of critical newsprint. (Later, when NASA spent more than \$1 million to acquire an additional two square kilometers for better frontage, the accusations of “special interests” were revived.) But the Houston area met all the technical criteria for the new center. The seventh (soon to be sixth) largest city in the country, Houston had the utilities, transportation, and weather, as well as all the cultural, academic, industrial, and recreational specifications.⁵⁹

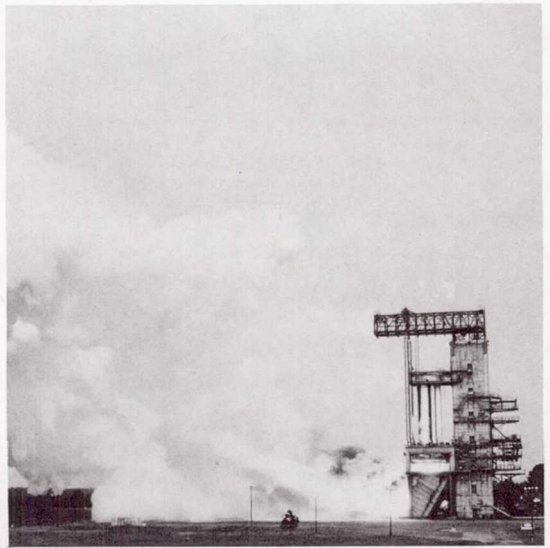
Webb knew that facilities and construction were critical to success in landing on the moon during the 1960s. He called on the Army Corps of Engineers for assistance, rather than face the costly and time-consuming struggle of staffing a NASA office for this one-time task. The Corps would be invaluable in acquiring land at both Merritt Island and Michoud and in constructing new facilities at the Cape, at Michoud, and at Houston. Webb asked Lieutenant General W. K. Wilson, Chief of Engineers, to join him in this enterprise almost as a partner.⁶⁰

Although the acquisition of real estate had demanded his close attention, the Administrator had never lost sight of the urgency of the Apollo launch vehicle and lunar landing mode questions. These needed to be resolved before the Corps of Engineers and NASA’s facilities engineers could do very much about designing the supporting installations.⁶¹

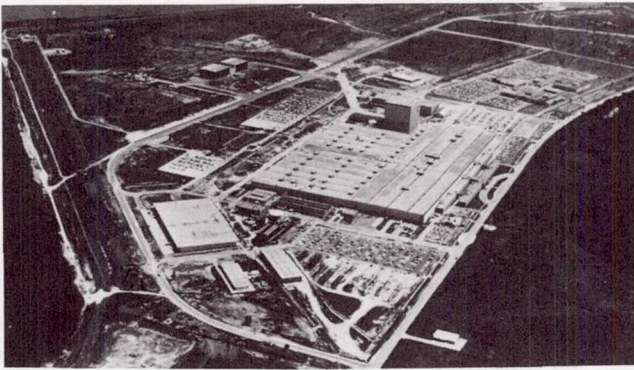
THE LAUNCH VEHICLE: QUESTION AND DECISION

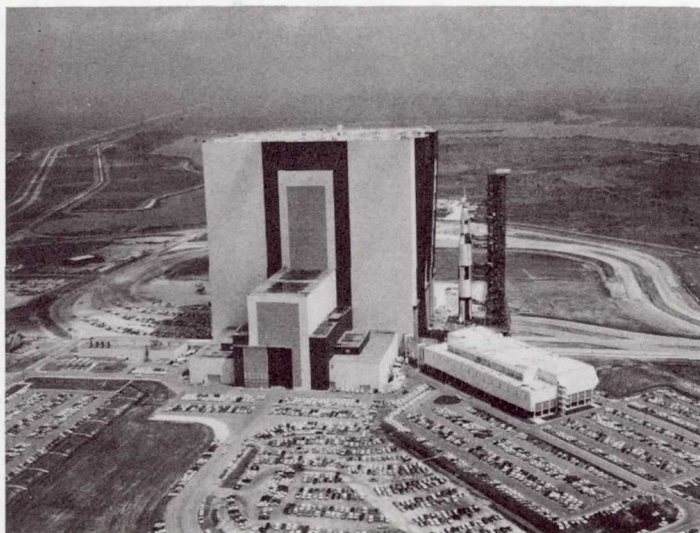
Late in September 1961, Webb announced a major reorganization of NASA, effective 1 November. Technical issues had to be resolved and leadership to be improved. Committees—no matter how many—could study

* Webb had written Gilruth in June 1961 that he seriously doubted NASA would be permitted to establish any large activity including several thousand more people in the Virginia area. Although no commitment had been made, Webb had learned from Congressman Thomas that Rice University in Houston had set aside 15 square kilometers of land for a research institution. Its location near the Houston ship channel made it highly desirable for NASA. Earlier, Don Ostrander had recommended to Seamans that the Space Task Group be moved to and combined with Marshall in Huntsville.

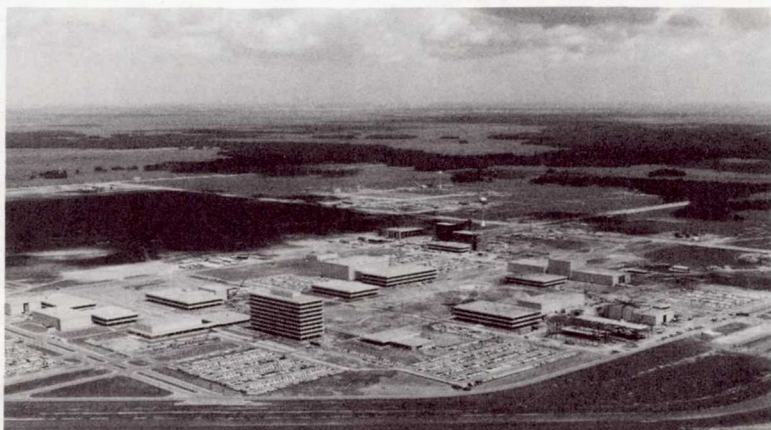


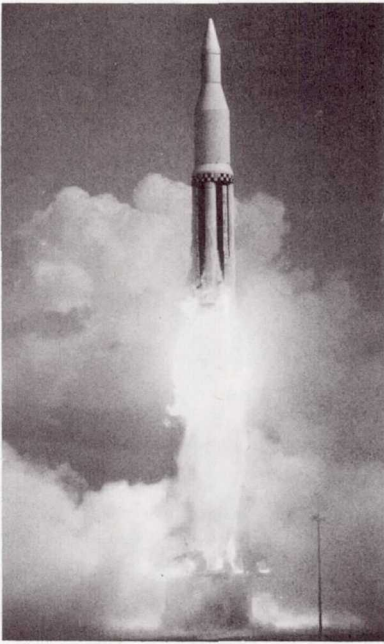
Booster stages for Redstone, Jupiter, and Saturn vehicles were tested at Redstone Arsenal near Huntsville, Alabama. Above, in 1960, Saturn C-1 first-stage engines are static-fired for the first time. When the Saturn booster grew in size, NASA obtained land in a less populated area, in Mississippi on the Pearl River near the Gulf of Mexico. In the 1968 photograph at upper left, test stands appear beside the waterways. To assemble the large Saturns, NASA needed a plant, preferably one already built. The Michoud facility (at lower left), close to New Orleans, suited the requirements. Inside Michoud in 1968 (below), Saturn IBs are on the assembly line.





Kennedy Space Center's Vehicle Assembly Building (above; earlier called the Vertical Assembly Building) stands high on Florida's Atlantic coast; the Saturn 500-F launch vehicle rides on a mobile crawler toward the launch pad in the 1966 photo. Modules of the Apollo spacecraft were tested in Florida in the Manned Spacecraft Operations Building. At right, NASA officials Walt Williams, Merritt Preston, Kurt Debus, Brainerd Holmes, and Wernher von Braun—assisted by Col. E. Richardson (Air Force) and Col. H. R. Parfitt (Army Corps of Engineers)—are ready to spade dirt, to mark the beginning of construction of the building in January 1963. Below is a 1964 photograph of the new Manned Spacecraft Center at Clear Lake near Houston.





Maiden launch of the Apollo program: Saturn SA-1 from Cape Canaveral, 27 October 1961.

problems and recommend solutions, but they could not make decisions or run a program.

Webb, Dryden, and Seamans had scoured the country for the right man to take charge of the Office of Manned Space Flight and Apollo. On 21 September, Webb appointed D. Brainerd Holmes as Director of OMSF, to head all manned space flight activity for Headquarters. Three days later, the Administrator announced a major shakeup at NASA's top levels that saw Silverstein return to Cleveland as Director of the Lewis Research Center.

Holmes was an electrical engineer who had been project manager for the ballistic missile early warning system across the Arctic Circle. He came to NASA from the Radio Corporation of America's Major Defense Systems Division. Webb and Holmes intended for Headquarters to take a larger part in Apollo than it had in Mercury. To strengthen this position, they hired Joseph F. Shea, from Space Technology Laboratories, Inc., as Holmes' deputy, to concentrate on systems engineering.

Apollo's acceleration brought an administrative change for the Space Task Group, in addition to the physical move from Virginia to Texas. Re-designated the Manned Spacecraft Center, it dropped its one-program image as a task force for Mercury and assumed its role as the center for all manned space flight programs. Gilruth continued as Director.⁶²

By November 1961, then, the agency had been reorganized to conduct the program more efficiently; sites and facilities had been identified to build, check out, support, and launch the lunar vehicles; and contracts had been awarded for the command section of the spacecraft, the guidance and navi-

gation system, and various engines and stages of the launch vehicle. Much of the Apollo puzzle had been pieced together, but the principal questions of booster configuration and mission mode were still unanswered, although there were hopes for a solution in the near future.

On 27 October, the engine cluster concept of launch vehicle stages was successfully demonstrated. A little after 10 in the morning, the eight barrels of the Saturn C-1 spewed flames as the booster lifted off from Cape Canaveral. This maiden launch of the program, carrying only dummy stages filled with water, augured well for a successful flight test program and for Apollo in general, but the 5.8 million newtons (1.3 million pounds) of thrust generated was far short of that needed to get men to the moon and back safely.⁶³

On 6 November, Milton Rosen (now NASA Director of Launch Vehicles and Propulsion) told Seamans and Holmes that he was setting up another special in-house committee to try to pin down the large launch vehicle development program. Although he admitted that he would be repeating much of the work of Golovin's Large Launch Vehicle Planning Group, Seamans and Holmes encouraged Rosen to proceed, hoping this committee might produce some tangible results.

The committee members* came almost entirely from Rosen's office. Noticeably lacking were spacecraft people, with only John Disher to represent them until David Hammock, of Gilruth's center, belatedly joined the group. The team examined specific areas—problems of orbital rendezvous, configuration of the advanced Saturn, plans for Nova, future potential of solid-fueled rocket motor development, and NASA's possible use for the Defense Department's Titan III.⁶⁴

Rosen's committee spent most of its two weeks of concentrated effort closeted in a motel room in Huntsville, near the Marshall center.⁶⁵ But, when Rosen reported to Holmes on 20 November, he had to concede that there were still differences within the committee on rendezvous versus direct flight and on solid versus liquid motors. He nonetheless contended that the group as a whole was in accord:

We took the view that the Golovin Committee had opened doors to a room which should be explored in order to formulate a program. Our report consists of a finer cut of the Golovin recommendations—it is more specific with regard to the content and emphasis of a program.⁶⁶

The Rosen Committee concluded that rendezvous (preferably a single operational maneuver) could be performed in either earth or lunar orbit,

* The committee consisted of Milton Rosen, Richard B. Canright, Eldon Hall, Elliott Mitchell, Norman Rafel, Melvin Savage, Adelbert O. Tischler, and John Disher (from Headquarters); William A. Mrasek, Hans H. Maus, and James B. Bramlet (Marshall); and David M. Hammock (Manned Spacecraft Center).

CHARIOTS FOR APOLLO

but the latter had the advantages of a single Saturn launch from the earth, using the C-4 or C-5, and a smaller, specially designed landing craft. A missed rendezvous, however, would prove fatal in lunar orbit. Moreover, the lunar lander, or ferry, which could place only a small payload on the moon, would permit a very limited staytime and would restrict the amount of scientific equipment that could be carried to the lunar surface. Although his group found earth orbit, where a missed rendezvous would mean only an aborted mission, more attractive, Rosen said, there was as yet no way of judging its difficulties or of estimating realistic schedules for development of docking and refueling techniques.

By this time, NASA officials in many quarters viewed the advanced Saturn as having at least four F-1 engines in its first stage. Rosen, convinced that NASA must build the biggest booster possible, recommended sliding a fifth engine in at the junction of two very strong crossbeams that supported the other four engines. With this extra power, he later said, either rendezvous mode—earth or lunar orbit—was possible.

Actually, Rosen himself favored direct flight; he believed it was a safer and surer way to reach the moon within the decade. He recommended the development of a Nova with eight F-1 engines in the first stage, which would be no more difficult, technically, than a five-engined Saturn.

Rosen's group opposed large solid-fueled rockets for manned lunar landing. There were too many technical problems to ensure a reasonable degree of reliability. Since the liquid-fueled F-1 and J-2 engines would be built for the Saturn C-5 anyway, why not use them in the Nova? The S-IVB stage should be used for the third stage of both the C-5 and Nova.⁶⁷

On 4 December 1961, Holmes learned that Seamans essentially agreed with the committee's recommendations.⁶⁸ Later in the month, Holmes established the Manned Space Flight Management Council—composed of himself, his principal subordinates at Headquarters, and senior officials from the manned space flight centers*—to set high-level policy for all manned space activities.⁶⁹ At its first meeting, on 21 December, the council voted to develop the Saturn C-5.⁷⁰

Early in January 1962, Holmes prepared a preliminary plan for the super-Saturn. He urged Seamans to release some of the money that had been authorized for an advanced Saturn, since negotiations with the three prospective contractors† were being delayed by the indefinite status of 1962 funding.⁷¹

In deciding on the C-5, the planners endowed the Apollo launch

* The Management Council comprised Holmes, Low, Rosen, Charles H. Roadman, William E. Lilly, and Joseph F. Shea (Headquarters); von Braun and Eberhard F. M. Rees (Marshall); and Gilruth and Walter C. Williams (Manned Spacecraft Center).

† The three were Boeing, first stage; North American, second stage; and Douglas, third (S-IVB) stage.

PROJECT PLANNING

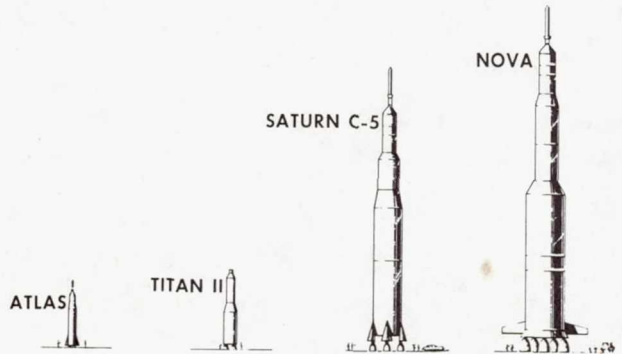
vehicle with flexibility. It could serve as the booster for earth-orbit, circum-lunar, and lunar-orbit missions. By launching two C-5s, a lunar landing could be made by earth-orbit rendezvous. And the C-5 seemed the best vehicle for the lunar-orbit rendezvous mode as well.⁷²

At the end of 1961, however, it was tacitly assumed at NASA Headquarters that the mode would be earth-orbit rendezvous. There was no distinct break, no real dividing line, marking the drift away from direct flight; the shift was so gradual that Seamans was unaware of the full import of changed feelings within the Office of Manned Space Flight and the field centers. "My own recollection is that we really kept both the direct ascent and the Earth orbit rendezvous as real possibilities," he later commented.⁷³

Paralleling the switch to earth-orbit rendezvous, with direct flight as a backup, was the broadening realization also that the physical and financial realities of designing, building, and testing both the C-5 and Nova, almost concurrently, were perhaps beyond NASA's—and the country's—economic ability.⁷⁴

When Holmes became chief of NASA's manned programs, he had been confronted with two pressing technical problems—mission approach and the launch vehicle for Apollo. Within a few weeks the management council had settled the vehicle configuration. Holmes then assigned Joseph Shea to investigate the mode question further.⁷⁵ Although earth-orbit rendezvous was gaining ground in Washington, the devotees of direct flight were not giving in easily. And in the field elements things were no better: Marshall was united on earth-orbit rendezvous, but the Manned Spacecraft Center was split between direct flight and lunar-orbit rendezvous. Actually, the mode issue had smoldered almost from the day NASA opened for business, creating camps that favored one route or another and raising passions of individual promoters to the point of conducting evangelical missions to gather converts. The next chapter explores some of the deep-seated prejudices.

Comparative sizes of manned space flight launch vehicles: Atlas for Mercury earth-orbital flight; Titan II for Gemini earth-orbital flight to perfect rendezvous procedures and study long-duration flight; Saturn C-5 chosen for Apollo; Nova, which would have been required for a direct flight landing on the moon.



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Contending Modes

1959 to Mid-1962

Politically setting a goal of manned lunar landing during the 1960s meant little technologically until somebody decided on the best way to fly there and back. Numerous suggestions had been made as to how to make the trip. Some sounded logical, some read like science fiction, and each proposal had vocal and persistent champions. All had been listened to with interest, but with no compelling need to choose among them. When President Kennedy introduced a deadline, however, it was time to pick one of the two basic mission modes—direct ascent or rendezvous—and, further, one of the variations of that mode. The story of Apollo told here thus far has only touched on the technical issues encountered along the tangled path to selecting the route.

PROPOSALS: BEFORE AND AFTER MAY 1961

NASA Administrator James Webb in early 1961 had inherited an agency assumption that direct ascent was probably the natural way to travel to the moon and back. It was attractive because it seemed simple in comparison to rendezvous, which required finding and docking with a target vehicle in space. But direct flight had drawbacks, primarily its need for the large rocket called Nova, which would be costly and difficult to develop. And the direct flight mission, itself, had been worked out only in the most general terms. At a meeting in Washington in mid-1960, the first NASA

CHARIOTS FOR APOLLO

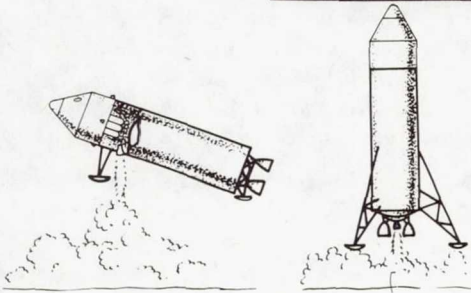
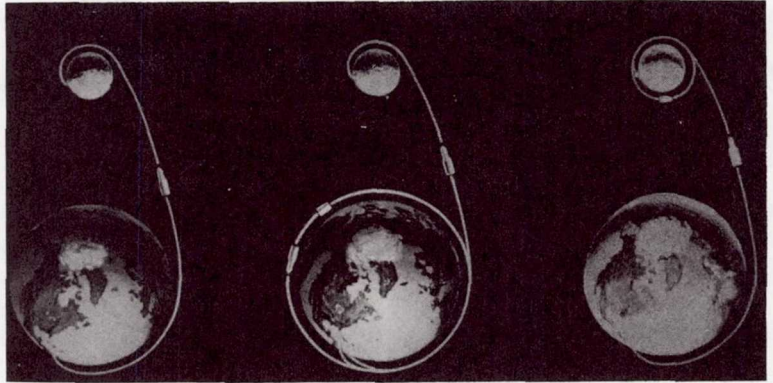
Administrator, Keith Glennan, had asked how a spacecraft might be landed on the moon. Max Faget of the Space Task Group had described a mission in which the spacecraft would first orbit the moon and then land, either in an upright position (on deployable legs) or horizontally (using skids on the descent stage). Wernher von Braun of Marshall and William Pickering of the Jet Propulsion Laboratory (JPL) thought it would be unnecessary to orbit the moon first. As Faget recalled, "Dr. Pickering [said] you don't have to go into orbit; . . . you just aim at the moon and, when you get close enough, turn on the landing rockets and come straight in. . . . I thought that would be a pretty unhappy day if, when you lit up the rockets, they didn't light."¹

Direct flight also had supporters outside NASA. The Air Force had worked since 1958 on a plan for a lunar expedition. Called LUNEX, this proposal evolved from the earlier "Man-in-Space-Soonest" studies that had lost out in competition with Project Mercury. Major General Osmond J. Ritland, Commander of the Space Systems Division of the Air Force Systems Command, viewed LUNEX as a way to satisfy "a dire need for a goal for our national space program." When President Kennedy announced on 25 May 1961 that a lunar landing would be that goal, the Space Systems Division offered to land three men on the moon and return them, using direct flight and a large three-stage booster. SSD believed the mission could be accomplished by 1967 at a cost of \$7.5 billion.²

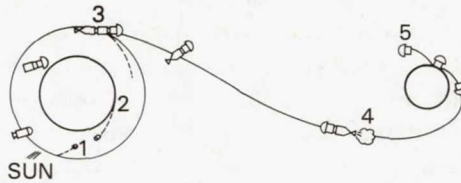
Rendezvous appeared dangerous and impractical to some NASA engineers, but to others it was the obvious way to eliminate the need for gigantic Nova-size boosters. Foremost among the variants in this approach was direct flight's chief competitor, earth-orbit rendezvous (EOR). The von Braun group had revealed an interest in this mode when it briefed Glennan in December 1958—long before its transfer from the Army to NASA. Von Braun had made a strong pitch for using EOR and the Juno V (later Saturn) booster, painting a pessimistic picture of developing anything large enough for direct ascent. Agreeing that direct flight was basically uncomplicated, von Braun nevertheless said he favored earth-orbit rendezvous because smaller vehicles could be employed. He sidestepped the problems of launching as many as 15 Saturns in rapid succession to rendezvous and dock in orbit to do the job.³

While working for the Army, the von Braun team published a study called "Project Horizon." Billed as a plan for establishing a lunar military outpost, Horizon justified bases on the moon in terms of the traditional military need for high ground, but it emphasized political and scientific gains as well. Again, the operational techniques would require launching several rockets and refueling a vehicle in earth orbit before going on to the moon.⁴

On 18 June 1959, NASA Headquarters had asked the Army Ballistic Missile Agency (ABMA) for a study by the von Braun team of a lunar



Three principal contending lunar landing techniques were suggested for the Apollo program: direct ascent, above left; earth-orbit rendezvous, above center; and lunar-orbit rendezvous. Sketched at the left are two landing techniques proposed for the direct ascent mode.

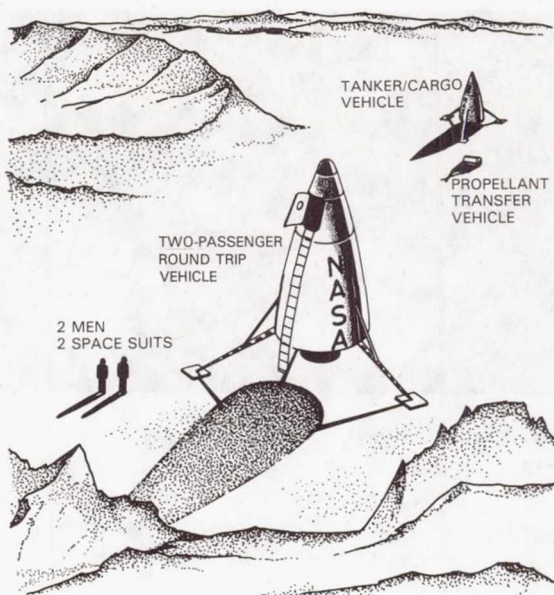


Earth-orbit rendezvous

1. Place propulsion unit in parking orbit
2. Place manned spacecraft in chasing ellipse
3. Launch assembled vehicle into lunar orbit
4. Brake vehicle for lunar landing
5. Return to earth

exploration program based on Saturn boosters. In its report of 1 February 1960, ABMA indicated there were several possibilities for a lunar mission, but only two—direct flight and earth-orbit rendezvous—seemed feasible. Reaffirming its authors' belief in rendezvous around the earth as the most attractive approach, the report continued: "If a manned lunar landing and return is desired before the 1970's, the SATURN vehicle is the only booster system presently under consideration with the capability to accomplish this mission." ⁵

After transferring to NASA and becoming the Marshall Space Flight Center, the von Braun group continued its plans for developing and perfecting its preferred approach. In January 1961, Marshall awarded 14 contracts for studies of launching manned lunar and planetary expeditions from earth orbit and for investigations of the feasibility of refueling in



In this proposed version of a lunar-surface-rendezvous procedure, a propellant-transfer vehicle takes fuel from the tanker to a manned space vehicle. After loading the fuel, the two astronauts would fire the engine of their spacecraft to return to the earth.

orbit.⁶ By mid-year, Marshall engineers were gathering NASA converts to help them push for earth-orbital rendezvous.

Across the country from Huntsville, another NASA center had different ideas about the best way to put man on the moon. Jet Propulsion Laboratory in Pasadena, California, suggested a link-up of vehicles on the moon itself. A number of unmanned payloads—a vehicle designed to return to earth and one or more tankers—would land on the lunar surface at a pre-selected site. Using automatic devices, the return vehicle could then be refueled and checked out by ground control before the crew left the earth. After the manned spacecraft arrived on the moon, the crew would transfer to the fully fueled return vehicle for the trip home. One of the earliest proposals for this approach was put together by Allyn B. Hazard, a senior development engineer at the laboratory. His 1959 scheme laid the groundwork for JPL's campaign for lunar-surface rendezvous during the Apollo mode deliberations.⁷

Even before the President's May 1961 challenge, Pickering had tried to sell lunar-surface rendezvous to NASA's long-range planners. Earlier that month, he had met in Washington with Abraham Hyatt, Director of Program Planning and Evaluation, to discuss this method of landing men on the moon. "We seriously believe," he later wrote, "that this is a better approach to getting man there quickly than the approaches calling for a very large rocket." Pickering favored this mode because the Saturn C-2 would be adequate for the job, unmanned spacecraft could develop the techniques of vertical descent and soft landings, NASA could space the launches months or even years apart, and the agency need not commit the manned capsule to

flight until very late in the program (and then only if everything else was working properly). He admitted that the small payload capability of the C-2 would restrict the early missions to one-man flights but contended that "it is easy to extend the technique for larger missions, as larger rockets become available."⁸ Hyatt assured Pickering that Headquarters would examine all suggested modes, while confessing to a certain incredulity about this approach. "The idea . . . leaves me with very strong reservations," Hyatt said.⁹

The fact that the United States had no large boosters in its inventory caused several farfetched schemes to surface. One such proposal promoted rendezvous and refueling while in transit to the moon, a concept pushed persistently by a firm named AstraCo. During the summer of 1960, AstraCo argued that this approach would "improve the mission capability of fixed-size earth launch systems." At the request of Senator Paul H. Douglas, NASA officials met with two of the company's representatives in Washington on 6 December 1960. After a discussion of the physical aspects of this kind of rendezvous and an analysis of fuel consumption and weight factors, the visitors were told that NASA was not interested. Three months later, on 14 March 1961, AstraCo took its case through another congressman to the NASA Administrator, and Webb asked his staff to take a second look. William Fleming and Eldon Hall calculated that rendezvous while on the way to the moon would save very little more weight and fuel than earth-orbit rendezvous and would be "far less reliable and consequently far more hazardous." Fleming recommended that this scheme be turned down, once and for all. Webb concurred.¹⁰

Another approach was the proposal to send a spacecraft on a one-way trip to the moon. In this concept, the astronaut would be deliberately stranded on the lunar surface and resupplied by rockets shot at him for, conceivably, several years until the space agency developed the capability to bring him back! At the end of July 1961, E. J. Daniels from Lockheed Aircraft Corporation met with Paul Purser, Technical Assistant to Robert Gilruth, to discuss a possible study contract on this mode. Purser referred Daniels to NASA Headquarters. Almost a year later, in June 1962, John N. Cord and Leonard M. Seale, two engineers from Bell Aerosystems, urged in a paper presented at an Institute of Aerospace Sciences meeting in Los Angeles that the United States adopt this technique for getting a man on the moon in a hurry. While he waited for NASA to find a way to bring him back, they said, the astronaut could perform valuable scientific work. Cord and Seale, in a classic understatement, acknowledged that this would be a very hazardous mission, but they argued that "it would be cheaper, faster, and perhaps the only way to beat Russia."¹¹ There is no evidence that Apollo planners ever took this idea seriously.

Amid these likely and unlikely suggestions for overcoming the country's limited booster capacity came yet another plan, lunar-orbit rendezvous

CHARIOTS FOR APOLLO

(LOR), which seemed equally outlandish to many NASA planners. As the name implies, rendezvous would take place around the moon rather than around the earth. A landing craft, a separate module, would descend to the lunar surface. When the crew finished their surface activities, they would take off in the lander and rendezvous with the "mother" ship, which had remained in orbit about the moon. They would then transfer to the command module for the voyage back to the earth.¹²

Early in 1959 this mode was seen primarily as a way to reduce the total weight of the spacecraft. Although most NASA leaders appreciated the weight saving, the idea of a rendezvous around the moon, so far from ground control, was almost frightening.

Perhaps the first identifiable lunar-orbit rendezvous studies were those directed by Thomas Dolan of the Vought Astronautics Division, near Dallas. In December 1958, Dolan assembled a team of designers and engineers to study vehicle concepts, looking for ways for his company to share in any program that might follow Project Mercury. From mid-1959, the group concentrated on lunar missions, including a lunar landing, as the most probable prospect for future aerospace business. Dolan and his men soon came up with a plan they called MALLAR, an acronym for Manned Lunar Landing and Return.

Dolan's group recognized very early that energy budgets were the keys to space flight (certainly no radical discovery). It conceived of a modular spacecraft, one having separate components to perform different functions. Dolan said, "One could perceive that some spacecraft modules might be applied to both Earth-orbital and lunar missions, embodying the idea of multimanned and multimodular approaches to space flight." With this as the cornerstone of a lunar landing program, Dolan concluded that the best approach was to discard the pieces that were no longer needed. And he saw no reason to take the entire spacecraft down to the lunar surface and back to lunar escape velocity. MALLAR therefore incorporated a separate vehicle for the landing maneuver.¹³

At the end of 1959 the Dolan team prepared a presentation for NASA. Early in January 1960, J. R. Clark, Vice President and General Manager of Vought Astronautics, wrote Abe Silverstein about Dolan's concept. The MALLAR proposal, Clark said, considered not only costs and vehicles but schedules. He also cited the advantages of the modular approach, mission staging, and the use of rendezvous.¹⁴

Nothing came of the proposal, although Dolan tried to interest NASA in MALLAR for the next two years. He found many technical people sympathetic to his ideas, but he was signally unsuccessful in winning financial support. He did get several small contracts from Marshall, but these were intended to bolster Marshall's stand on rendezvous in earth orbit. Vought tried in vain to win part of Apollo, first competing for the feasibility study contracts in the latter half of 1960 and then, a year later, teaming with

McDonnell Aircraft Corporation on the spacecraft competition. Because of these failures, Dolan and his group gradually lost the support of their corporate management.¹⁵ Thereafter, Chance Vought mostly faded out of the Apollo picture—although the company competed (and lost) once more, when the lunar landing module contracts were awarded in 1962.¹⁶

LOR GAINS A NASA ADHERENT

At Langley Research Center, several committees were formed during 1959 and 1960 to look at the role of rendezvous in space station operations.* John Houbolt, Assistant Chief of the Dynamic Loads Division, who headed one of these groups, fought against being restricted to studies of earth-orbiting vehicles only. The mission the Houbolt team wanted to investigate was a landing on the moon.¹⁷

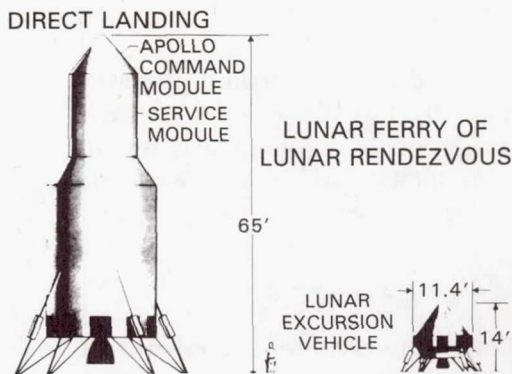
A more formal Lunar Missions Steering Group was established at Langley during 1960, largely through the efforts of Clinton E. Brown, Chief of the Theoretical Mechanics Division. The Lunar Trajectory Group within Brown's division made intensive analyses of the mechanics in a moon trip. Papers on the subject were presented to the steering group and then widely disseminated throughout Langley.¹⁸

One of these monographs, by William Michael, described the advantage of parking the earth-return propulsion portion of the spacecraft in orbit around the moon during a landing mission. Michael explained that leaving this unit, which was not needed during the landing, in orbit would save a significant weight over that needed for the direct flight method; the lander, being smaller, would need less fuel for landing and takeoff. But he cautioned that this economy would have to be measured against the "complications involved in requiring a rendezvous with the components left in the parking orbit."¹⁹

Brown's steering group looked closely at total weights and launch vehicle sizes for lunar missions, comparing various modes. Arthur Vogeley, in particular, concentrated on safety, reliability, and potential development programs; Max Kurbjun studied terminal guidance problems; and John Bird worked on designs for a lander. They concluded that lunar rendezvous was the most efficient mode they had studied.²⁰

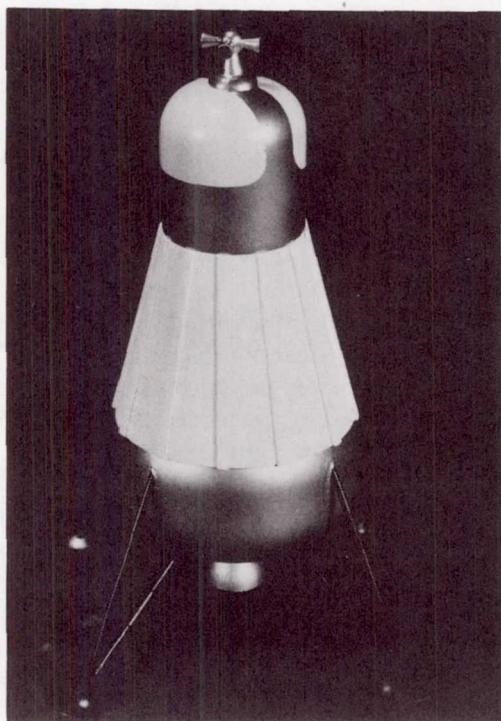
Work at Langley then slackened somewhat, since NASA's manned lunar landing plans seemed to be getting nowhere. On 14 December 1960, however, personnel from Langley went to Washington to brief Associate Administrator Robert Seamans on the possible role of rendezvous in the

* Most deeply engaged in Langley's rendezvous studies were John Bird, Max C. Kurbjun, Ralph W. Stone, Jr., John M. Eggleston, Roy F. Brissenden, William H. Michael, Jr., Manuel J. Queijo, John A. Dodgen, Arthur Vogeley, William D. Mace, W. Hewitt Phillips, Clinton E. Brown, and John C. Houbolt.



A ferry that would leave a command ship in orbit around the moon, visit the lunar surface, and then return to the command ship for the voyage back to the earth could be smaller than the lander required for direct landing on the moon or other suggested modes. The reduced size was seen by many engineers as the great advantage of lunar orbit rendezvous over the other techniques.

An early lunar excursion model was designed on a Friday afternoon in early 1961 by John D. Bird and Ralph W. Stone, Jr., of Langley Research Center for project MALLIR.



national space program. When he first joined NASA, three months earlier, Seamans had toured the field centers. At Langley, Houbolt had given him a 20-minute talk on lunar-orbit rendezvous, using rough sketches to illustrate his theory. Seamans had been sufficiently impressed by this brief discussion to ask Houbolt and his colleagues to come to Washington in December and make a more formal presentation. At this meeting, Houbolt spoke on the value of rendezvous to space flight; Brown presented an analysis of the weight advantages of lunar-orbit rendezvous over direct flight; Bird talked about assembling components in orbit; and Kurbjun gave the results of some simulations of rendezvous, indicating that the maneuver would not be very difficult.

Houbolt closed the session, remarking that rendezvous was an undervalued technique so far, but NASA should seriously consider its worth to the lunar landing program. Several members of Seamans' staff viewed the weight-saving claims with skepticism,²¹ but Seamans was understanding. He

had just completed a study for the Radio Corporation of America on the interception of satellites in earth orbit, and it occurred to him that some of the concepts he had studied might well be adapted to lunar operations.²²

Back in Virginia, the Langley researchers had been trying to get their Space Task Group neighbors interested in rendezvous for Apollo. On 10 January 1961, Houbolt and Brown briefed Kurt Strass, Owen Maynard, and Robert L. O'Neal. O'Neal, who reported to Gilruth on the meeting, was less than enthusiastic about the lunar-orbit rendezvous scheme. He conceded that it might reduce the weight 20 percent, but "any other than a perfect rendezvous would detract from the system weight saving."²³

From December 1960 to the summer of 1961, Langley continued its analyses of lunar-orbit rendezvous as it applied to a manned lunar landing. Bird and Stone, among others, studied hardware concepts and procedures, including designs and weights for a lunar lander, landing gear, descent and ascent trajectories between the landing site and lunar orbit, and final rendezvous and docking maneuvers. Their findings were distributed in technical reports throughout NASA and in papers presented to professional organizations and space flight societies.²⁴

In the spring of 1961, these Langley engineers compiled a paper proposing a three-phase plan for developing rendezvous capabilities that would ultimately lead to manned lunar landings: (1) MORAD (Manned Orbital Rendezvous and Docking), using a Mercury capsule to prove the feasibility of manned rendezvous and to establish confidence in the techniques; (2) ARP (Apollo Rendezvous Phase), using Atlas, Agena, and Saturn vehicles to develop a variety of rendezvous capabilities in earth orbit; and (3) MALLIR* (Manned Lunar Landing Involving Rendezvous), employing Saturn and Apollo components to place men on the moon. Houbolt urged that NASA implement this program through study contracts.²⁵

EARLY REACTION TO LOR

When the special NASA committees in 1961 (see Chapter 2) were trying to get the Apollo program defined, Houbolt made the rounds, making certain that everyone knew of Langley's lunar-orbit rendezvous studies. At a meeting of the Space Exploration Program Council on 5 and 6 January, his arguments for lunar rendezvous were lost in the attention being given to direct flight and earth-orbit rendezvous.²⁶

In Washington on 27 and 28 February, when Headquarters sponsored an intercenter rendezvous meeting, Houbolt again summarized Langley's

* MALLIR embodied lunar-orbit rendezvous and a separate landing craft. Because America had no launch vehicle large enough to send a craft to the moon with only one earth launch, it also required an earth-orbital rendezvous before the spacecraft departed on a lunar trajectory.

CHARIOTS FOR APOLLO

recent efforts. But both the Gilruth and von Braun teams stood solidly behind their respective positions, direct flight and earth-orbit rendezvous. Houbolt later recalled his frustration when it seemed lunar-orbit rendezvous "just wouldn't catch on."²⁷

On 19 May, Houbolt bypassed the chain of command and wrote directly to Seamans to express his belief that rendezvous was not receiving due consideration. He pointed out that the American booster development program was in poor shape and that NASA appeared to have no firm plans beyond the initial version of the Saturn, the C-1. Houbolt was equally critical of NASA's failure to recognize the need for developing rendezvous techniques. Because of the lag in launch vehicle development, he said, it seemed obvious that the only mode available to NASA in the next few years would be rendezvous.²⁸

In June Houbolt, a member of Bruce Lundin's group—the first team specifically authorized to examine anything except direct flight—talked to the group about his concept. Although the Lundin Committee initially seemed interested in Houbolt's description of lunar-orbit rendezvous, only lunar-surface rendezvous scored lower in its final report.²⁹

During July and August, Houbolt had almost the same reaction from Donald Heaton's committee. Although this group had been instructed to study rendezvous, the members interpreted that mandate as limiting them to the earth-orbit mode. Houbolt, himself a member of the committee, pleaded with the others to include lunar-orbit rendezvous; but, he later recalled, time after time he was told, "No, no, no. Our charter [applies only to] Earth orbit rendezvous." Some of the members, seeing how deeply he felt about the mode question, told him to write his own report to Seamans, explaining his convictions in detail.

Growing discouraged at the lack of interest, Houbolt and his Langley colleagues began to see themselves as sole champions of the technique. They decided to change their tactics. "The only way to do it," Houbolt said later, was "to go out on our own, present our own documents and our own findings, and make our case sufficiently strong that people [would] have to consider it."³⁰

Houbolt felt that things were looking up when the Space Task Group asked him to prepare a paper on rendezvous for the Apollo Technical Conference in mid-July 1961. At the dry run, however, when he and the other speakers presented their papers for final review, Houbolt was told to confine himself to rendezvous in general and to "throw out all [that] LOR."³¹

The next opportunity Houbolt had to fight for his cause came when Seamans and John Rubel established the Golovin Committee. Nicholas Golovin and his team were supposed to recommend a set of boosters for the national space program, but they found this an impossible task unless they knew how the launch vehicles would be used. This group was one of

the first to display serious interest in Langley's rendezvous scheme. At a session on 29 August, when Houbolt was asked, "In what areas have you received the most violent criticism of these ideas?" he replied:

Everyone says that it is hard enough to perform a rendezvous in the earth orbit, how can you even think of doing a lunar rendezvous? My answer is that rendezvous in lunar orbit is quite simple—no worries about weather or air friction. In any case, I would rather bring down 7,000 pounds [3200 kilograms] to the lunar surface than 150,000 pounds [68 000 kilograms]. This is the strongest point in my argument.³²

Realizing that he at last had his chance to present his plan to a group that was really listening, Houbolt called John Bird and Arthur Vogeley, asking them to hurry to Washington to help him brief the Golovin Committee. Afterward the trio returned to Langley and compiled a two-volume report, describing the concept and outlining in detail a program based on the lunar-orbit mode. Langley's report was submitted to Golovin on 11 October 1961. After it had been thoroughly reviewed, its highlights were discussed, favorably, in the Golovin report.³³

Instead of resting after his labors with the Golovin Committee, Houbolt went back to Langley and the task of getting out his minority report on the Heaton group's findings. He submitted it to Seamans in mid-November, with a cover note that said, in part, "I am convinced that man will first set foot on the moon through the use of ideas akin to those expressed herein."³⁴ His report to Seamans, a nine-page indictment of the planning for America's lunar program to date, was a vigorous plea for consideration of Langley's approach.

"Somewhat as a voice in the wilderness," he began, "I would like to pass on a few thoughts on matters that have been of deep concern to me over the recent months." Houbolt explained to Seamans that he was skipping the proper channels because the issues were crucial. After recounting his attempts to draw the attention of others in NASA to the lunar-orbit rendezvous scheme, Houbolt noted that, "regrettably, there was little interest shown in the idea."

He went on to ask, "*Do we want to get to the moon or not?*" If so, why not develop a lunar landing program to meet a given booster capability instead of building vehicles to carry out a preconceived plan? "Why is NOVA, with its ponderous [size] simply just accepted, and why is a much less grandiose scheme involving rendezvous ostracized or put on the defensive?" Noting that it was the small Saturn C-3 that was the pacing item in the lunar rendezvous approach, he added, parenthetically, "I would not be surprised to have the plan criticized on the basis that it is not grandiose enough."

A principal charge leveled at lunar-orbit rendezvous, Houbolt said,

CHARIOTS FOR APOLLO

was the absence of an abort capability, lowering the safety factor for the crew. Actually, he argued, the direct opposite was true. The lunar-rendezvous method offered a degree of safety and reliability far greater than that possible by the direct approach, he said. But "it is one thing to gripe, another to offer constructive criticism," Houbolt conceded. He then recommended that NASA use the Mark II Mercury in a manned rendezvous experiment program and the C-3 and lunar rendezvous to accomplish the manned lunar landing.³⁵

Seamans replied to Houbolt early in December. "I agree that you touched upon facets of the technical approach to manned lunar landing which deserve serious consideration," Seamans wrote. He also commended Houbolt for his vigorous pursuit of his ideas. "It would be extremely harmful to our organization and to the country if our qualified staff were unduly limited by restrictive guidelines." The Associate Administrator added that he believed all views on the best way to carry out the manned lunar landing were being carefully weighed and that lunar-orbit rendezvous would be given the same impartial consideration as any other approach.³⁶

ANALYSES OF LOR

Most of the early criticism of the lunar rendezvous scheme stemmed from a concern for overall mission safety. In the minds of many, rendezvous—finding and docking with a target—would be a difficult task even in the vicinity of the earth. This concern was the underlying reason for the trend toward larger and larger Saturns (C-2 through C-5) to lessen the number of maneuvers required. (After all, von Braun had once suggested that as many as 15 launchings of the smaller launch vehicles might be needed for one mission.) During earth-orbital operations, the crew could return to the ground if they failed to meet their target vehicle or had other troubles. In lunar orbit, where the crew would be days away from home, a missed rendezvous spelled death for the astronauts and raised the specter of an orbital coffin circling the moon, perhaps forever. And all this talk about rendezvous came at a time when NASA had only a modicum of space flight experience of any kind. It is not surprising, therefore, that Houbolt had trouble swinging others away from their advocacy of direct flight or earth-orbit rendezvous.

Fears for crew safety and lack of experience were not the only factors; the Langley approach was criticized on another score—one as damning as the danger of a missed rendezvous. One of the principal attractions of Houbolt's mode was the weight reduction it promised; but he and his colleagues, in trying to sell the mode, had oversold this aspect. Many who listened to the Langley team's proposals simply did not believe the weight

figures cited, especially that given for the lunar landing vehicle. In the lunar mission studies at Vought Astronautics, Dolan and his team had given much thought to designing the hardware, including a landing vehicle. Their weight calculations for a two-man lunar landing module were much higher than those proposed by the Langley engineers. Vought's study projected a 12 000-kilogram vehicle, most of which was fuel. Empty, the lander would weigh only 1300 kilograms.³⁷

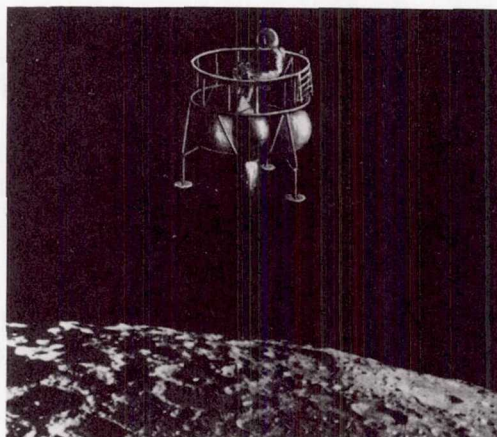
But, until late 1961, no one in NASA except Langley had really looked very hard at lunar landing vehicles. Using theoretical analyses and simulations, the rendezvous team at the Virginia center had studied hardware, "software" (procedures and operational techniques), flight trajectories, landing and takeoff maneuvers, and spacecraft systems (life support, propulsion, and navigation and guidance).³⁸ The studies formed a solid foundation for technical design concepts for a landing craft.

Langley's brochure for the Golovin Committee described landers of varied sizes and payload capabilities. There were illustrations and data on a "shoestring" vehicle, one man for 2 to 4 hours on the moon; an "economy" model, two men and a 24-hour stay time; and a "plush" module, two men for a 7-day visit. Weight estimates for the three craft, without fuel, were 580, 1010, and 1790 kilograms, respectively. Arthur Vogeley pictured the shoestring version as a solo astronaut perched atop an open rocket platform with landing legs. To expect Gilruth's designers to accept such a "Buck Rogers space scooter" would seem somewhat optimistic.³⁹

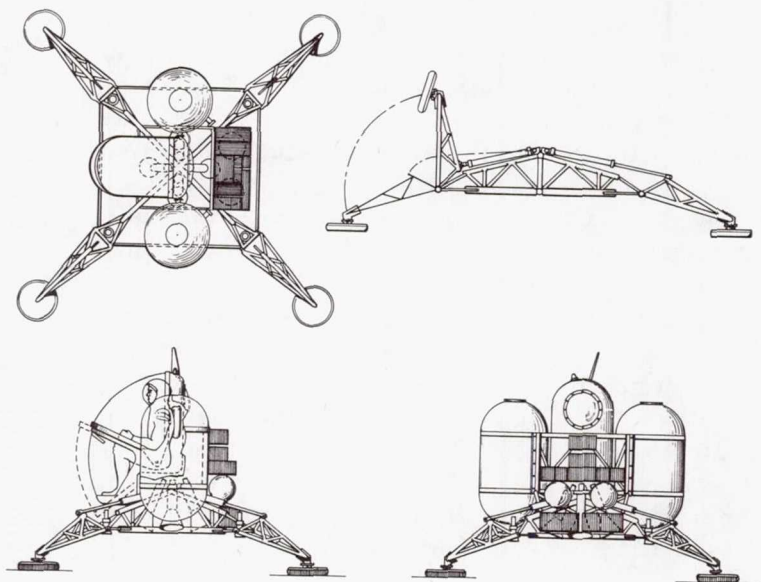
The same sort of minimal design features extended to subsystems, and structural weights further reflected Langley's drive toward simplicity. In February 1961, at NASA's intercenter rendezvous conference, Lindsay J. Lina and Vogeley had described the most rudimentary navigation and guidance equipment: a plumb bob, an optical sight, and a clock. This three-component system was feasible, they said, "only because maximum advantage is taken of the human pilot's capabilities." Even some of those on the Langley team criticized this kind of thinking; John Eggleston, for one, labeled it impractical.⁴⁰

Despite Houbolt's frustration, his missionary work had stimulated interest outside Langley. Within the Office of Manned Space Flight, George Low, Director of Spacecraft and Flight Missions, commented that "the 'bug' approach may yet be the best way of getting to the moon and back."⁴¹ And Houbolt had finally struck a responsive chord when giving his sales talk to the Space Task Group in August. At this briefing, James Chamberlin, Chief of the Engineering Division, had been very attentive and had requested copies of the Langley documents. All during the year, Chamberlin and his team had been working on a study of putting two men in space in an enlarged Mercury capsule (which later emerged as Project Gemini).⁴²

Although this successor to Mercury had been conceived as earth-orbital



	<u>LB</u>
1 MAN AND LIFE SUPPORT	220
CONTROLS	50
STRUCTURE	230
ENGINE AND TANKAGE	220
FUEL AND OXIDIZER	2500
TOTAL	3220



The sketch (top) is an artist's concept of a small lunar lander during descent to the surface of the moon, as proposed by Langley Research Center employees in October 1961. The engineering drawings were made by Harry C. Shoaf (Space Task Group Engineering Division) 15 November 1961 of a proposed lunar lander to be used with an advanced version of the Mercury spacecraft.

and long-duration, Chamberlin thought it might fly to the moon, as well. Seamans recalled that Chamberlin "was trying to develop something that was almost competitive with the Apollo itself." Chamberlin did, indeed, offer an alternative to Apollo. He and several of his colleagues proposed using the two-man craft and lunar rendezvous in conjunction with a one-man lunar lander, which in many respects resembled the small vehicles studied by Langley.⁴³

Although Chamberlin could get approval only for the earth-orbital part of his plan, one of his principal objectives—rendezvous—was highly significant. It marked the beginning of the first important shift in the Apollo mode. Gilruth and his engineers began to perceive advantages they had not previously appreciated.

Growing interest in lunar-orbit rendezvous stemmed partially from disenchantment with direct flight. The Space Task Group had become increasingly apprehensive about landing on the moon in one piece and with enough fuel left to get back to earth. The command section it had under contract was designed as an earth-orbital, circumlunar, and reentry vehicle. It could not fly down to the surface of the moon. Lunar rendezvous, which called for a separate craft designed for landing, became more inviting.⁴⁴

Gilruth's engineers had worked on several designs for a braking rocket for lunar descent. In a working paper released in April 1961, Apollo planners had tried to size a propulsion system for landing, even though no booster had yet been chosen to get it to the moon. Two methods for landing were explored. The first was to back the vehicle in vertically, using rockets to slow, then stop, the spacecraft, setting it down on its deployed legs. The second technique was to fly the spacecraft in horizontally, like an aircraft. In this case, the legs would be deployed from the side of the craft instead of from the bottom.⁴⁵

In the summer of 1961, when the command module contract was being advertised, Max Faget described some of the problems he anticipated with the landing itself. All other phases of the mission could be analyzed with a fair degree of certainty, he said, but the actual touchdown could not, since there was no real information on the lunar surface. Exhaust from rocket engines on loose rocks and dust might damage the spacecraft, interfere with radar, and obstruct the pilot's vision. Faget said the final hovering and landing maneuvers must be controlled by the crew to ensure landing on the most desirable spot. The Apollo development plan, in its many revisions, merely said that the lunar landing module would be used for braking, hovering, and touchdown, as well as a base for launching the command ship from the moon.⁴⁶

About the time of the contract award, Abe Silverstein left NASA Headquarters to become Director of Lewis Research Center.⁴⁷ It had become increasingly apparent that Apollo would probably use one rendezvous

CHARIOTS FOR APOLLO

scheme or another, and he was among the staunchest advocates of big booster power and direct flight. Concurrently with Silverstein's return to Cleveland, Lewis was assigned to develop the lunar landing stage. Gilruth and Faget did not like this division of labor, as it added a complex management setup to the technical difficulties of matching spacecraft and landing stage.

Faget proposed a different propulsion module from the one previously envisioned for the descent to the lunar surface. He suggested taking the legs off the landing module and making it into just a braking stage, which he called a "lunar crasher." Once this stage had eased the spacecraft down near the surface, it would be discarded to crash elsewhere before the Apollo touched down. The Apollo spacecraft would then consist of the command center and two propulsion modules, one to complete the landing and the other to boost the command module from the surface. Since the crasher's only job was to slow the spacecraft, it was not part of the vehicle's integral systems, which decreased the technical interfaces required and minimized Lewis' role in the hardware portion of Apollo. Faget based his proposal on some sound technical reasoning. The crasher engines would be pressure-fed, no pumps would be needed, and the vehicle could be controlled by turning the engines off and on as long as the propellant lasted. Pump-fed engines, on the other hand, depended on complex interactions to vary the thrust. Faget and Gilruth liked the pressure-fed system, and so did Silverstein.⁴⁸

Although relations with Lewis were easier after the adoption of the crasher, the Houston engineers were still worried about the complexities of an actual landing. As Faget later said, "We had all sorts of little ideas about hanging porches on the command module, and periscopes and TV's and other things, but the business of eyeballing that thing down to the moon didn't really have a satisfactory answer. . . . The best thing about the [lunar rendezvous concept] was that it allowed us to build a separate vehicle for landing."⁴⁹ Caldwell Johnson, one of the chief contributors to the Apollo command module design, had much the same reaction. He said, "We continued to pursue the landing with a big propulsion module and the whole command and service module for a long, long time, until it finally became apparent that this wasn't going to work."⁵⁰

By the end of 1961, the newly named Manned Spacecraft Center had virtually swung over to the lunar-orbit rendezvous idea. Gilruth, Faget, and the other Apollo planners conceded that this approach had drawbacks: a successful rendezvous with the mother craft after the bug left the lunar surface was an absolute necessity, and only two of the three crew members would be able to land on the moon. But the stage had been set for an intensive campaign to sell the von Braun team on this mode. At Headquarters, Director of Manned Space Flight Holmes wanted the two manned space

flight centers to agree on a single route—he did not expect to get this consensus easily.⁵¹

SETTLING THE MODE ISSUE

At the beginning of 1962, Holmes was not sure how he would vote on the lunar landing technique. Von Braun, among others, had made it clear that direct ascent, requiring the development of a huge Nova vehicle, was too much to ask for within the decade. However, both earth- and lunar-orbit rendezvous appeared equally feasible for accomplishing the moon mission within cost and schedule constraints. The decision, Holmes knew, would require weighing many technological factors. After directing Joseph Shea, his deputy for systems, to review the issue and recommend the best approach, Holmes laid down a second and broader objective. Shea was to use the task to draw Huntsville and Houston together, building a more unified organization with greater internal strength and cooperation.⁵²

In mid-January 1962, Shea visited both the Manned Spacecraft and the Marshall Space Flight Centers. He found Houston officials enthusiastic about lunar-orbit rendezvous but believed they did not fully understand all the problems. He reported their low weight estimates as unduly optimistic. Marshall, on the other hand, still favored earth-orbit rendezvous. Shea did not think the Huntsville team had really studied lunar-orbit rendezvous thoroughly enough to make a decision either way.

From these brief sorties, Shea recognized the depth of the technical disagreement between the centers. He decided to bring the two factions together and make them listen to each other. During the next few months, Shea held a series of meetings at Headquarters, attended by representatives from all the centers working on manned space flight. At these briefings, the advocates presented details of their chosen modes to a captive audience. The first of these gatherings, featuring earth-orbit rendezvous, was held on 13 to 15 February 1962.⁵³

Headquarters may not have realized it, but the sense of urgency surrounding the mode question was shared by the field. Recognizing that the need for choosing a mission approach was crucial, Gilruth's men hastened to strengthen their technical brief. The Houston center notified Headquarters in January that it was going to award study contracts on two methods of landing on the moon, with either the entire spacecraft or a separate module, hoping one of the contractors would do a good enough job to be chosen as a sole source for a development contract.⁵⁴ But Washington moved before the center could act.

Holmes and Shea had decided that lunar rendezvous needed further investigation. A contract supervised by Headquarters would tend to be more

CHARIOTS FOR APOLLO

objective than one monitored by the field. A request for proposals was drawn up and issued at the end of January, and a bidders' conference was held on 2 February in Washington. Although this contract was small, it was critical, and representatives from a dozen aerospace companies attended the conference. Those intending to bid were given only two weeks to respond. Shea and his staff, with the help of John Houbolt, evaluated the proposals and announced on 1 March that Chance Vought had been selected.⁵⁵

Chance Vought's study ran for three months and was significant mainly because of its weight estimates. Houston calculated that the target weight of the lunar landing module would be 9000 kilograms, but Chance Vought came up with a more realistic figure of 13 600 kilograms. Shea and his team, in the subsequent mode comparisons, used Chance Vought's higher weight projections.⁵⁶

Holmes' Management Council was also studying the mission approach. On 6 February, with Associate Administrator Seamans present, the group heard another of Houbolt's briefings on lunar- versus earth-orbit rendezvous. Charles Mathews, Chief of the Spacecraft Research Division, then described Houston's studies of the lunar-rendezvous mode. Von Braun interjected that selection of any rendezvous method at that time was premature.⁵⁷

On 27 March, the council discussed the Chance Vought study. Several of the members were concerned about the weight the contractor was estimating the Saturn C-5 would have to lift, compared with that projected by the Houston center (38 500 kilograms against 34 000). This disparity was very serious, since Chance Vought's work would be useless if Marshall decided that the C-5 could not manage the heavier load. The council also noted that the mode issue was beginning to affect other elements of the program adversely. North American was designing the service module to accommodate either form of rendezvous; but, as more detail was incorporated into the design, being able to go both ways would cost more in weight and complexity.⁵⁸

On 2 and 3 April, Shea called field center officials to a meeting on lunar-orbit rendezvous. After some basic ground rules for operations and hardware designs had been laid down, it became obvious to Shea that there were still too many unresolved questions. He told the company to go back home and continue the studies.⁵⁹

About this time, a small group in Houston took up the campaign for lunar-orbit rendezvous waged earlier by Houbolt. Charles W. Frick, who headed the newly formed Apollo Spacecraft Project Office at Manned Spacecraft Center, had aerospace management experience in both research and manufacturing—first at Ames Research Center for NASA and then with General Dynamics/Convair for industry. Frick saw Marshall, rather than Headquarters, as the strategic target for an offensive. Frick said, "It became

apparent that the thing to do was to talk to Dr. von Braun, in a technical sense, . . . perhaps with a bit of showmanship, and try to convince him.”⁶⁰

During February 1962, Frick and his project office staff briefed Holmes on why they favored lunar rendezvous. Frick ruefully admitted later that they did a rather poor job. “So when we got back [to Houston] we got our heads together and decided that we just weren’t putting down [enough] technical detail.” He formed a small task force, drawn from his own project people and Max Faget’s engineering directorate, to pull the information together.⁶¹

William Rector of Frick’s office got busy on this more persuasive presentation. The result, a carefully staged affair that became known as “Charlie Frick’s Road Show,” consisted of briefings by half a dozen speakers. The opening performance was staged in Huntsville before von Braun and his subordinates on 16 April 1962. To emphasize the importance of the message, the Houston group included all of the leading lights of the center—Gilruth, his top technical staff, and several astronauts—as well as senior Apollo officials from North American (the command module contractor).

In a day-long presentation, Frick’s troupe explained three technical reasons for his center’s conversion to lunar-orbit rendezvous: (1) highest payload efficiency, (2) smallest size for the landing module, and (3) least compromise on the design of the spacecraft. The advantages of a separate lander (all listed in Houbolt’s minority report to Seamans), which would neither take off from nor land on the earth, loomed large, since Gilruth and his men believed that landing on the moon would be the most difficult phase of Apollo and they wanted the simplest landing possible.⁶²

Frick and his road company next headed for Washington, where they gave two performances—for Holmes on 3 May and for Seamans on 31 May.⁶³ The Houston center’s drive to sell lunar rendezvous thus followed the path traveled by Houbolt a year earlier. Although it doubtless reinforced his arguments, it appeared to have no other effect.

In budgetary hearings before Congress in the spring of 1962, NASA officials named earth-orbit rendezvous as the best mode for Apollo, with direct flight as the backup. NASA Deputy Administrator Dryden said, on 16 April, “As we see it at the moment, we are putting our bets on a rendezvous [in earth orbit] with two advanced Saturn’s.” However, Dryden continued, “if we find that we are not able to do this mission by rendezvous, we would be in a bad way.”⁶⁴

When asked by members of the House Subcommittee on Manned Space Flight about approaches other than earth-orbit rendezvous and direct flight, Holmes admitted that lunar rendezvous was also interesting. The mission could theoretically be performed with a single Saturn C-5, Holmes went on, but it was considered too hazardous, since failure to rendezvous around the moon would doom the crew.⁶⁵

CHARIOTS FOR APOLLO

Early in May, yet another scheme for landing men on the moon appeared. A study for a direct flight, using a C-5 and a two-man crew, had been quietly considered at the Ames and Lewis Research Centers and at North American. Although there were objections from Houston, Shea hired the Space Technology Laboratories to investigate this C-5 direct mode.⁶⁶

Other researchers at Ames spent a great deal of time on plans that revealed their dislike of lunar rendezvous. Alfred Eggers and Harold Hornby, in particular, traded information and mulled over rendezvous modes with North American engineers. Hornby favored a method that resembled von Braun's December 1958 idea, arguing the advantages of some sort of salvo rendezvous in earth orbit. When he realized that NASA Headquarters was on the brink of making the mode decision, Eggers kept urging Seamans to reopen the whole question of the safest, most economical way to reach the moon.⁶⁷

Shea, having promised Holmes a preliminary recommendation on the mode by mid-June, increased the pressure on the field centers to continue their research for the coordination meetings. On 25 May Holmes asked the Directors of the three manned space flight centers to submit cost and schedule estimates for each of the approaches under consideration.⁶⁸ Shea began collecting his material for final review, although there was still no agreement between Huntsville and Houston. Despite Frick's road show, the Marshall center persisted in its preference for earth-orbit rendezvous. The mode comparison meetings had obviously been less than successful in bringing the two opponents together. "I was pretty convinced now that you could do either EOR or LOR," Shea later said, "so the choice . . . was really . . . what's the best way."⁶⁹

Holmes and Shea, in addition to deciding on the best approach, were still determined to settle for nothing short of unanimity. They scheduled yet another series of meetings at each center, "in which we asked them to summarize their studies and draw conclusions" so everyone would feel like a real part of the technical decision process.⁷⁰

Shortly before these summary meetings in May and June of 1962, the mounting tide of evidence favoring lunar-orbit rendezvous reached its flood. Shea and Holmes became convinced that this was indeed the best approach. But, if they were to have harmony within their organization, Marshall must be won over. Holmes asked Shea to discuss lunar-orbit rendezvous in depth with von Braun and to explore his reaction to the crimp this mode would put in Marshall's share of Apollo. Since lunar rendezvous would require fewer boosters than the earth-orbital mode and since Marshall would have no part in developing docking hardware and rendezvous techniques, the Huntsville role would diminish considerably. Also, with the Nova's prospects definitely on the wane, Marshall's long-term future seemed uncertain.

For some time von Braun and his colleagues had wanted to broaden the scope of their space activities, and Holmes knew it. He and Shea de-

cided that this was the time to offer von Braun a share of future projects, including payloads, to balance the workload between Houston and Huntsville.

About the middle of May, von Braun visited Washington, and Shea told him that lunar rendezvous appeared to be shaping up as the best method. Conceding that it might well be a wise choice, the Marshall Director again expressed concern for the future of his people. Shea acknowledged that Marshall would lose a good deal of work if NASA adopted lunar rendezvous, but he reminded von Braun that

Houston would be very loaded with both the CSM [command and service modules] and the LEM [lunar excursion module]. It just seems natural to Brainerd and me that you guys ought to start getting involved in the lunar base and the roving vehicle and some of the other spacecraft stuff. . . . Wernher kind of tucked that in the back of his mind and went back to Huntsville.⁷¹

Huntsville was not the only center that faced a loss of business if lunar-orbit rendezvous were chosen. Lewis would also be left standing at the gate, since that mode would eliminate the need for the lunar crasher. The Cleveland group did hope to capitalize on liquid hydrogen and liquid oxygen technology for other pieces of the Saturn propulsion requirements, although this, of course, would mean a contest with Marshall.⁷²

The Management Council met in Huntsville on 29 May, two weeks after the confidential talk between Shea and von Braun. Perhaps in compliance with his implied promise to the Marshall Director, Shea opened the subject of an unmanned logistics vehicle to deposit supplies on the moon, increasing the time that a manned spacecraft could remain on the lunar surface. George Low warned that developing a logistics vehicle should not be a prerequisite to a manned lunar landing.⁷³ Houston questioned the usefulness of unmanned supply craft "because of the reliability problems of unmanned vehicles, and . . . whether supplies [previously deposited] on the moon could be effectively used." Gilruth's men argued that any such vehicle should not simply be an Apollo lunar excursion vehicle modified for unmanned operation. The best approach would be a "semisoft" lander, similar to unmanned spacecraft like Surveyor. And Gilruth's engineers were quick to point out that logistic support could be obtained by attaching a "mission module" to a manned lunar module, since the Saturn C-5 should eventually be able to handle an additional 1600 kilograms of supplies and equipment.⁷⁴

Shea's special meetings on the centers' mode studies resumed in early June. By far the most significant was an all-day affair at Marshall on 7 June, where von Braun's lieutenants catalogued the latest results of their research.

"The tone of everything [throughout the day] in the presentations by

CHARIOTS FOR APOLLO

his people was all very pro-EOR," Shea recalled. At the end, after six hours of discussion on earth-orbit rendezvous, von Braun dropped a bomb that, as far as internal arguments in NASA were concerned, effectively laid the Apollo mode issue to rest. To the dismay of his staff, said Shea, von Braun "got up and in about a 15-minute talk that he'd handwritten during the meeting stated that it was the position of [his] Center to support LOR."⁷⁵

"Our general conclusion," von Braun told his startled audience, "is that all four modes are technically feasible and could be implemented with enough time and money." He then listed Marshall's preferences: (1) lunar-orbit rendezvous, with a recommendation (to make up for its limited growth potential) to begin simultaneous development of an unmanned, fully automatic, one-way C-5 logistics vehicle; (2) earth-orbit rendezvous, using the refueling technique; (3) direct flight with a C-5, employing a lightweight spacecraft and high-energy return propellants; and (4) direct flight with a Nova or Saturn C-8. Von Braun continued:

I would like to reiterate once more that *it is absolutely mandatory that we arrive at a definite mode decision within the next few weeks*. . . . If we do not make a clear-cut decision on the mode very soon, our chances of accomplishing the first lunar expedition in this decade will fade away rapidly.

The Marshall chief then explained his about-face. Lunar rendezvous, he had come to realize, "offers the highest confidence factor of successful accomplishment within this decade." He supported Houston's contention that designing the Apollo reentry vehicle and the lunar landing craft were the most critical tasks in achieving the lunar landing. "A drastic separation of these two functions into two separate elements is bound to greatly simplify the development of the spacecraft system [and] result in a very substantial saving of time."

Moreover, lunar-orbit rendezvous would offer the "cleanest managerial interfaces"—meaning that it would reduce the amount of technical coordination required between the centers and their respective contractors, a major concern in any complex program. Apollo already had a "frightening number" of these interfaces, since it took the combined efforts of many companies to form a single vehicle. And, finally, this mode would least disrupt other elements of the program, especially booster development, existing contract structures, and the facilities already under construction.

We . . . readily admit that when first exposed to the proposal of the Lunar Orbit Rendezvous mode we were a bit skeptical. . . .

We understand that the Manned Spacecraft Center was also quite skeptical at first, when John Houbolt of Langley advanced the proposal, . . . and it took quite a while to substantiate the feasibility of the method and finally endorse it.

CONTENDING MODES

Against this background it can, therefore, be concluded that the issue of "invented here" versus "not invented here" does not apply to either the Manned Spacecraft Center or the Marshall Space Flight Center; that both Centers have actually embraced a scheme suggested by a third source. Undoubtedly, personnel of MSC and MSFC have by now conducted more detailed studies on all aspects of the four modes than any other group. Moreover, it is these two Centers to which the Office of Manned Space Flight will ultimately have to look to "deliver the goods." I consider it fortunate indeed . . . that both Centers, after much soul searching, have come to identical conclusions. This should give the Office of Manned Space Flight some additional assurance that our recommendations should not be too far from the truth.⁷⁶

CASTING THE DIE

Von Braun's pronouncement in favor of lunar-orbit rendezvous, thus aligning his center with Gilruth's in Houston, signaled the accord that Holmes and Shea had so meticulously cultivated. Von Braun's conversion brought the two centers closer together, paving the way for effective cooperation. "It was a major element in the consolidation of NASA," Shea said.⁷⁷

Thereafter, ratification of the mode question—the formal decision-making process and review by top management—followed almost as a matter of course. The Office of Systems began compiling information from the field center studies, adding the result of its own mode investigations. Shea and his staff also listened to briefings from several aerospace companies who had studied lunar rendezvous and the mission operations and hardware requirements for that approach. These firms, among them Douglas and a team from Grumman and RCA, believed that such work might enhance their chances of securing the additional hardware contracts that would follow a shift to lunar rendezvous.⁷⁸

Shea's staff then compared the contending modes and prepared cost and schedule estimates for each. It appeared that lunar-orbit rendezvous should cost almost \$1.5 billion less than either earth-orbit rendezvous or direct flight (\$9.2 billion versus \$10.6 billion) and would permit lunar landings six to eight months sooner.⁷⁹

The Office of Systems issued the final version of the mode comparison at the end of July. This was the foundation upon which Holmes would defend his choice. Comparison of the modes revealed no significant technical problems; any of the modes could be developed with sufficient time and money, as von Braun had said. But there was a definite preferential ranking.

Lunar rendezvous, employing a single Saturn C-5, was the most advantageous, since it also permitted the use of a separate craft designed solely

CHARIOTS FOR APOLLO

for the lunar landing. In contrast, earth rendezvous with Saturn C-5s had the least assurance of mission success and the greatest development complexity of all the modes. Direct flight with the Nova afforded greater mission capability but demanded development of launch vehicles far larger than the C-5. A scaled-down, two-man C-5 direct flight offered minimal performance margins and portended the greatest problems with equipment accessibility and checkout. Therefore, "the LOR mode is recommended as most suitable for the Manned Lunar Landing Mission."⁸⁰

On 22 June, Shea and Holmes had presented their findings to the Management Council. After extended discussions, the council unanimously agreed that lunar-orbit rendezvous was the best mode. To underscore the solidarity within the manned space flight organization, all of the members decided to attend when Administrator Webb was briefed on the mode selection.⁸¹

First, however, Holmes and Shea informed Seamans of the decision. "By then," the Associate Administrator recalled, "I was thoroughly convinced myself, and everybody agreed on it." This was a technical decision that, from a general management position, he had refused to force upon the field organizations, even though he had long thought that lunar rendezvous was preferable.⁸²

On 28 June, Webb listened to the briefing and to the recommendations of the Management Council. He agreed with what was said but wanted Dryden, who was in the hospital, to take part in the final decision. That night, Seamans, Holmes, and Shea called on Dryden in his sickroom. Dryden had opposed lunar rendezvous because of the risks he believed it entailed, but he, too, liked the unanimity within the council and within NASA and gave lunar-orbit rendezvous his blessing.⁸³

Although acceptance of lunar rendezvous by the agency came before the end of June 1962, it was not announced until the second week in July. The delay was caused by outside pressure. PSAC, the President's Science Advisory Committee, headed by Jerome Wiesner, had developed an interest in NASA's launch vehicle planning and the mode selection for Apollo. Wiesner had formed a special group, the Space Vehicle Panel, to keep an eye on NASA's doings, and Nicholas Golovin, no longer with NASA, worked closely with this panel. Wiesner had hired Golovin for PSAC because of his familiarity with the internal workings of the agency and his knowledge of the country's space programs, both military and civilian. Golovin led a persistent and intensive review of Apollo planning that caused considerable turmoil within the agency and forced it into an almost interminable defense of its decision to use lunar rendezvous. Concurrently with Shea's drive for field center agreement, the PSAC panel was holding meetings in Huntsville and Houston, demanding that the two centers justify their stand on lunar-orbit rendezvous. The panel then insisted on meeting with Shea and his staff in Washington for further discussions.⁸⁴

CONTENDING MODES

In a memorandum on 10 July, approved by both Webb and Dryden, Seamans officially informed Holmes that the decision on the Apollo mode had been approved. The Rubicon was crossed; Apollo was to proceed with lunar rendezvous. Immediate development of both the Saturn C-1B and a lunar excursion vehicle was also approved. Seamans added that "studies will be undertaken on an urgent basis" to determine the feasibility of earth-orbit rendezvous using the C-5 and a two-man capsule, one "designed, if possible, for direct ascent . . . as a backup mode."⁸⁵

Webb, Seamans, Holmes, and Shea announced the selection of lunar-orbit rendezvous for Apollo at a news conference on 11 July 1962. Webb, perhaps as a concession to Wiesner, warned that the decision was still only tentative; during the forthcoming months, he added, the agency would solicit proposals for the lunar landing module from industry and would study them carefully before making a final decision. In the meantime, studies of other approaches would continue.

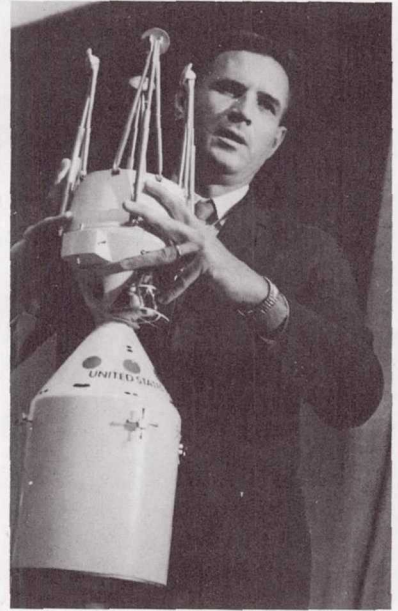
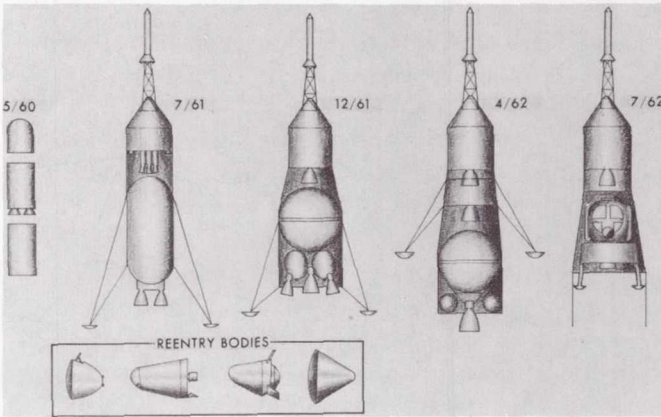
Holmes, however, struck a more definite note on the finality of the decision. Anything so complex, so expensive, as Apollo had to be studied at length, he said. "However, there is a balance between studying a program . . . and finally implementing it. There comes a point in time, and I think the point in time is now, when one must make a decision as to how to proceed, at least as the prime mode."

Webb concluded the press briefing:

We have studied the various possibilities for the earliest, safest mission . . . and have considered also the capability of these various modes . . . for giving us an increased total space capability.

We find that by adding one vehicle to those already under development, namely, the lunar excursion vehicle, we have an excellent opportunity to accomplish this mission with a shorter time span, with a saving of money, and with equal safety to any other modes.⁸⁶

Early the next morning, Holmes and Shea appeared before the House Committee on Science and Astronautics to explain NASA's seemingly abrupt abandonment of earth-orbit rendezvous. Holmes said, "It was quite apparent last fall this mission mode really had not been studied in enough depth to commit the tremendous resources involved, financial and technical, for the periods involved, without making . . . detailed system engineering studies to a much greater extent than had been possible previously." Nor had there been any agreement within the agency on any approach; "further study was necessary for that reason," as well. But investigations could go on forever, he added, and "at some point one must make a decision and say now we go. It has been really impossible for us to truly



NASA announced selection of the lunar-orbit-rendezvous landing technique at an 11 July 1962 press conference. At the conference table, left to right above, are NASA Administrator James E. Webb, Associate Administrator Robert C. Seamans, Jr., Office of Manned Space Flight Director D. Brainerd Holmes, and OMSF Director of Systems Joseph F. Shea. At lower left are major configuration changes in the Apollo spacecraft from May 1960 to July 1962. The inset reentry bodies illustrate shapes that received the greatest amount of study. At right, Shea uses models to demonstrate how the lunar module would dock with the command module.

program manage [Apollo] until this primary mode decision had been made." Although several modes were workable, lunar-orbit rendezvous was "the most favorable one for us to undertake today." Equally important was the new rapport that had been achieved within the manned space flight organization "to get the whole team pulling together."⁸⁷

"Essentially," Holmes told an American Rocket Society audience a week later, "we have now 'lifted off' and are on our way."⁸⁸ But the PSAC challenge to NASA's choice still had to be dealt with before the decision became irreversible. While fending off this outside pressure, NASA had to keep North American moving on the command and service modules, watch MIT's work on the navigation and guidance system, and find a contractor for the lunar landing module.

4

Matching Modules and Missions

1962

During 1962, NASA faced three major tasks: keeping North American moving on the command and service modules, defending its decision to fly the lunar-orbit rendezvous mode, and finding a contractor to develop the separate landing vehicle required by that approach.

North American engineers spent the opening months of the year at desks, at drawing boards, and in conference rooms. Although not all the pieces of the Apollo stack had been defined, the first job was obviously to build a three-man earth-orbital spacecraft. This Phase A or Block I version, already worked out by NASA in considerable depth, still required detailed analyses, precise engineering specifications, and special manufacturing tools. The contractor also had to make scale-model spacecraft for wind-tunnel tests and full-size mockups of wood and metal for study and demonstration uses.¹

THE TEAM AND THE TOOLS

Harrison A. Storms, Jr. (widely known as "Stormy"), Vice President of North American and President of its Space and Information Systems Division, was a forceful leader in advanced design and development work and a vigorous decision-maker who got things done. He had studied aeronautical engineering under Theodore von Kármán at the California Institute of Technology during the 1940s. Subsequently, at North American,

CHARIOTS FOR APOLLO

he had advanced steadily through the ranks. With the nationally famous test pilot A. Scott Crossfield, among others, Storms had shepherded the company team through the first phases of the X-15 and later the XB-70 aircraft programs.²

John Paup, who had worked at North American for several years before joining Sperry Rand, returned to his former employer in mid-1961 to help Storms bid on the NASA proposals and to become general manager for Apollo.³ Paup, in turn, picked Norman J. Ryker, Jr., as his chief designer. Ryker, who had joined the company in 1951, had been a stress analyst on the pioneer Navajo missile. He had also helped prepare bids for contracts for the Ranger and Surveyor spacecraft. North American had lost these competitions, but Ryker had remained in advanced design work.⁴

Charles H. Feltz, a company man since 1940, was a fourth major leader of North American's Apollo development team. He had worked on P-51 and B-25 aircraft during the Second World War and later on the B-45, the F-86, and the F-100. Feltz had been project leader on the X-15 rocket research aircraft, coming into close contact with NACA and then NASA leaders with whom he would work on Apollo. Feltz was considered by his peers to be one of the best manufacturing managers in the airframe business.⁵

In the days before Project Mercury, North American, with General Electric, had been under contract to the Air Force for "Man-in-Space-Soonest." When the Air Force lost the manned space flight mission to NASA, North American had put in a bid for Mercury. After losing to the McDonnell Aircraft Corporation in 1959, North American officials in 1961 were not eager to chance another defeat in a major NASA competition. But Storms and Paup, after combining forces with Ryker and Feltz, were determined to try for Apollo. When NASA picked North American on 11 September 1961 to build the S-II second stage of the advanced Saturn, J. Leland Atwood, President of the corporation, and Samuel K. Hoffman,



A team and a goal: officials of North American Aviation, Inc., study a replica of the moon shortly after the announcement that NASA had selected NAA as prime contractor for the Apollo command and service modules. From left to right are Harrison A. Storms, president of North American's Space and Information Systems Division; John W. Paup, program manager for Apollo; and Charles H. Feltz, Apollo program engineer.

MATCHING MODULES AND MISSIONS

President of the firm's Rocketdyne Division, were reconciled to this role in the program. Storms, Paup, and Ryker were not; they pressed on to win the spacecraft contract as well.⁶

Storms' team operated from a two-story building in Downey, California. Design engineers and draftsmen occupied the major portion of the structure, their desks crowded together in cavernous halls. An adjacent building housed the manufacturing activities for the space division. Ninety percent of the property belonged to the federal government, but long-term leases had made North American, as tenant, virtually the proprietor. Now, with the Apollo contract, plans were made to recruit personnel, to buy adjoining property, and to construct more buildings and facilities. In the meantime, some of the personnel worked out of house-trailer offices in the parking lots.

The manpower buildup in Storms' division in the first six months of 1962 doubled the size of his organization—from 7000 to more than 14 000 persons. Although many employees were busy on the Air Force's Hound Dog missile, among other projects, the newcomers for the most part were hired to develop the Apollo command and service modules.⁷

One of the first structures built at Downey specifically for Apollo began to take shape early in 1962. The Impact Test Facility, 46 meters high, looked like a gigantic playground swing. It was a swing of sorts—one designed to hold and drop a command module so the Apollo team could study it and improve structural strengths of the heatshield, honeycomb shock absorbers, inner and outer shells, afterbody, and astronaut couches. At one end of the swing was a pool of water, at the other a sandpile that could be banked or pitted with gravel and boulders. To return men safely from the moon required a knowledge of the exact limits they and their machine could endure at the final landing on earth.⁸

As expected, structures, heatshields, and radiation protection were primary concerns during the first year or so. Unexpectedly, however, the manufacture of mockup modules, initially considered of less importance, quickly grew into a major program to supply boilerplate spacecraft (metal models designed to be used in testing). North American's structural assembly department had begun tooling up for extensive work on mockups in January 1962. By the end of the year, this shop employed 305 persons on three shifts, tooling, drilling, welding, and assembling custom-built units. D. W. Chidley, a 14-year veteran of North American's prototype manufacturing and head of the department, reported at year's end that his group had built six test vehicles and two full-scale mockups, which had been featured in NASA-North American reviews during the year.⁹

To keep key personnel ready for the frequent meetings with NASA and aware of daily plant operations, Storms, Paup, Ryker, and Feltz held ten-minute briefings for all plant supervisors at the beginning of each morning shift. Agendas were carefully controlled; no interruptions were permitted; and everyone was required to speak for his section. Thus, until

CHARIOTS FOR APOLLO

North American's Apollo operation grew too large to make this kind of communication useful, all the major managers had at least one daily direct contact with their colleagues and superiors. Some of these sessions were devoted to plans for selecting and working with the subcontractors who would develop the subsystems.¹⁰

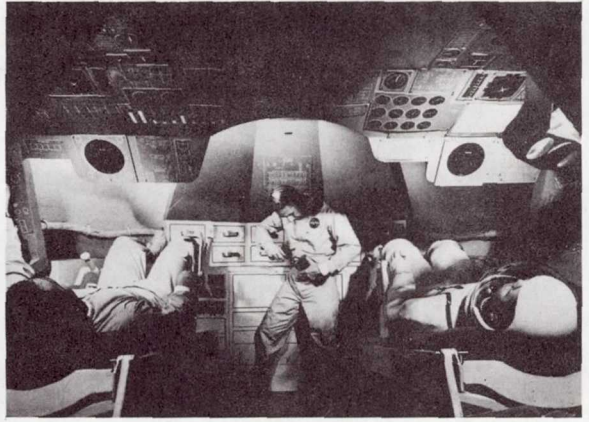
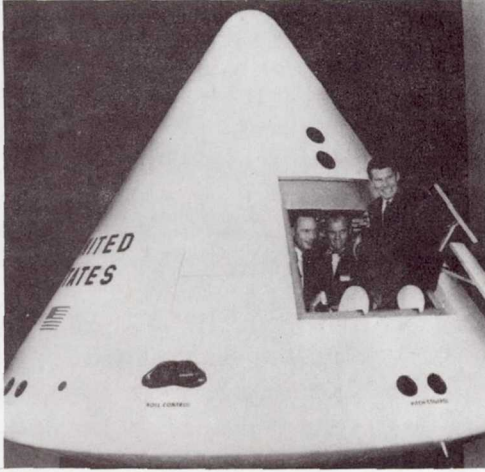
Shortly after the NASA-North American contract was signed, subcontractors for four of the spacecraft systems were picked: (1) Collins Radio Company for telecommunications; (2) The Garrett Corporation's AiResearch Manufacturing Company, environmental control; (3) Minneapolis-Honeywell Regulator Company, stabilization and attitude control; and (4) Northrop Corporation's Radioplane (later Ventura) Division, parachutes and earth landing.

North American soon added other subcontractors. In February 1962 the Lockheed Propulsion Company was selected to design the solid-propellant motor for the launch escape tower. By the end of March, The Marquardt Corporation had been chosen for the command and service modules' reaction control system, Aerojet-General for the service module's main engine, and Avco Corporation for ablative coatings and the spacecraft heatshield. In April, Thiokol Chemical Corporation was named to work with Lockheed on the launch escape system.¹¹

While NASA was trying to decide on the mode during the first half of 1962, John Paup and his North American engineers were getting restive. Although repeatedly warned by his own people not to bend tin or cut metal too soon, Paup insisted that hardware production should get under way. He did have his model shops turn out a mockup of a lunar excursion

The North American Aviation plant (below) at Downey, California, developed and produced the Apollo command module. The impact facility (right) at North American was used to drop-test the CM on water, sand, gravel, and boulders to check structural integrity and impact loads.





Interior of a partial full-scale mockup of the Apollo command module, above. In flight, the center couch would be removed (as shown), giving better access to the instrument panel and lower equipment bay. At left, left to right, astronauts Scott Carpenter, John Glenn, and Walter Schirra in 1963 inspect a full-scale mock-up of the Apollo CM, designed for three men.

module—which looked like a helicopter cab atop thin spidery legs—and of a lunar braking module, just in case a direct route to the moon should be chosen. On the first of June, Paup wrote Houston that schedules for spacecraft delivery were slipping further and further behind. How could they build the service module, he asked, if they did not know what it would be used for?¹²

But there was at least one area where work could start immediately. Early in the contract, North American and Houston engineers had agreed on a flight-test program, putting boilerplate command and service modules through structural tests and checking out the abort escape system. In mid-1961, while he was still with NASA (before joining North American in 1962), Alan Kehlet had suggested using a fin-stabilized, clustered-rocket, solid-propellant booster for these tests. The “Little Joe II” (named after the Project Mercury test vehicle) would be able to propel a full-sized Apollo reentry spacecraft to velocities as great as those in the critical portions of the Saturn trajectory and to altitudes of 60 900 meters. The tests would be a simple and fairly inexpensive way of determining—in flight—the full-scale spacecraft configuration concepts, systems performance, and structural integrity. Tests of the launch escape system at maximum dynamic pressure would be most important. In May 1962 the Convair Division of General Dynamics was selected to develop the vehicle.¹³

Although launch sites at Wallops Island, Virginia; Eglin Air Force Base, Florida; and the Cape were considered, the New Mexico desert north of El Paso, Texas, was picked early in the spring of 1962 as the Little Joe

CHARIOTS FOR APOLLO

II test area. The Army's White Sands Missile Range (WSMR) seemed the most suitable for Little Joe II ballistic flights.¹⁴

NASA engineers expected to conduct three kinds of tests at White Sands: (1) pad aborts, in which a solid-fueled rocket mounted on a tower attached to the top of the command module would pull the spacecraft away as it would have to do if the Saturn threatened to blow up on the launch pad; (2) maximum-dynamic-pressure ("max q") tests, in which the rocket would pull the spacecraft away from the launch vehicle if the booster veered off course shortly after launch; and (3) high-altitude tests, in which the rocket would haul the spacecraft away from the launch vehicle if the Saturn were unable to boost its payload to orbital flight.¹⁵

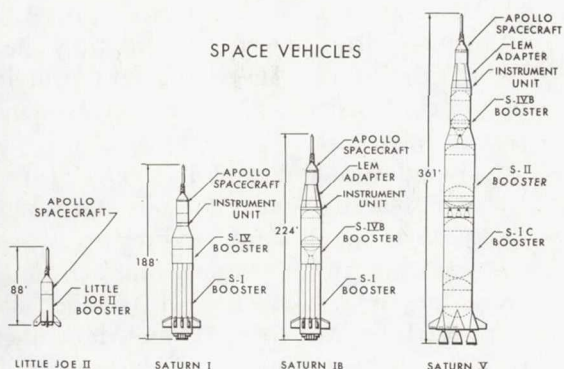
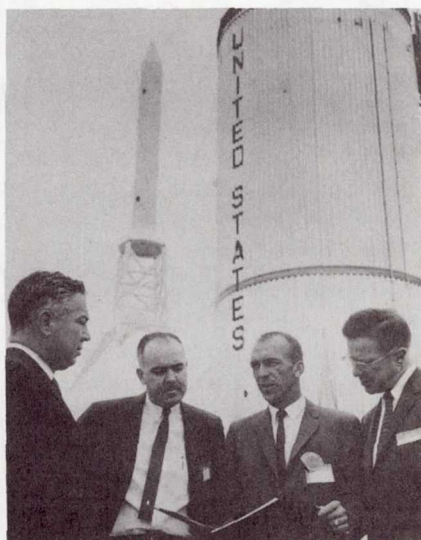
Other organizations, such as the Ames Research Center, near San Francisco, had been working on Apollo while waiting for a mode decision. Quite often after a day's work at Downey, North American engineers flew to Moffett Field, carrying models for Ames to test in its wind tunnels. Ames engineers were also dropping test vehicles on a simulated lunar surface to study landing gear designs and possible structural damage on impact.¹⁶

Ames had a close relationship with its Navy neighbors at Moffett Field. Navy flight surgeon Harald A. Smedal, who had been in aviation medicine for years, was a logical consultant to NASA's research engineers. Interested in physiological instrumentation as well as pilot performance during flight, Smedal worked on spacecraft cabin designs, especially on cockpit layouts that emphasized pilot convenience in spacecraft control.¹⁷

Another example of Ames' applied research that fed into North American was the work of test pilots and life scientists in ground-based simulations of the characteristics of spacesuits, restraint harnesses, work-rest cycles, and isolation conditions. North American and Ames were intent on making certain that the cockpit was designed to take full advantage of the pilots' capabilities in performing and sharing their duties.¹⁸

The Lewis Research Center in Cleveland, Ohio, also took a hand in getting spacecraft development on a good footing by putting Marquardt's reaction control jets through a test program. These small motors—used to turn the spacecraft right or left, up or down, or in a roll maneuver—were cooled regeneratively (in a process in which the expansion of part of the hot gas cools the remainder). When tests showed that the engines would burn up during reentry heating, Houston directed North American to use Marquardt motors only on the service module (since it would be jettisoned before reentry) and to make or buy command module jets similar to the ablative engines developed for Gemini. In August 1962, the command module thruster contract was transferred to North American's Rocketdyne Division, which produced Gemini's attitude control and maneuvering engines and reentry control system.¹⁹

Even though the Manned Spacecraft Center had gained its independence and had moved away, the ties between NASA-Langley and NASA-



General Dynamics' Little Joe II program manager Jack Hurt (holding book above) discusses development and production plans with NASA officials (left to right) Walter Williams, Robert Piland, and James Elms at the San Diego plant in May 1963. Selection of Little Joe II completed the Apollo family of launch vehicles. A desert area at White Sands Test Facility, New Mexico, was used for testing the spacecraft propulsion system module.



A pad abort test at White Sands, left, helped determine that the launch escape system could propel the Apollo command module away from danger if a Saturn launch vehicle explosion should threaten. A model of the CM, below, launched by a Little Joe II in 1965, is recovered after impact on the New Mexico desert.



CHARIOTS FOR APOLLO

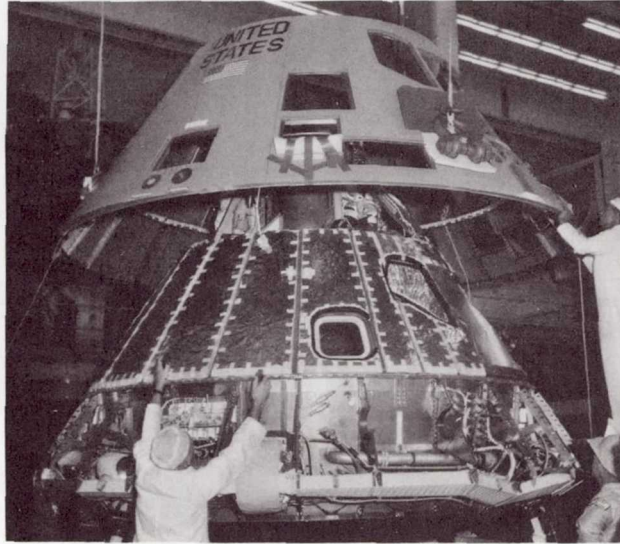
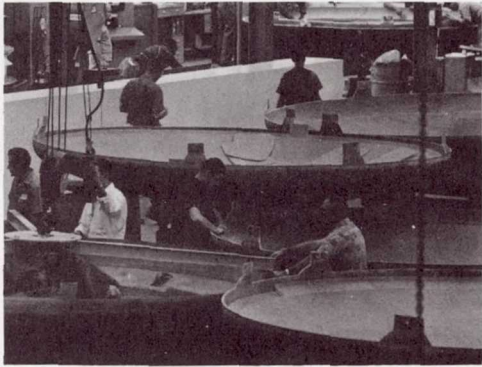
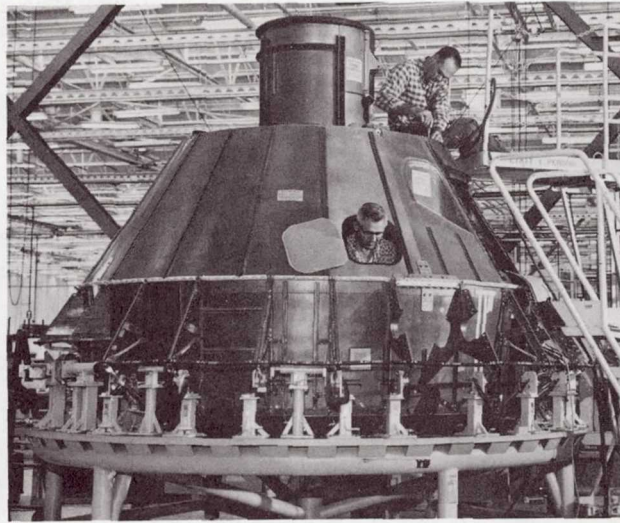
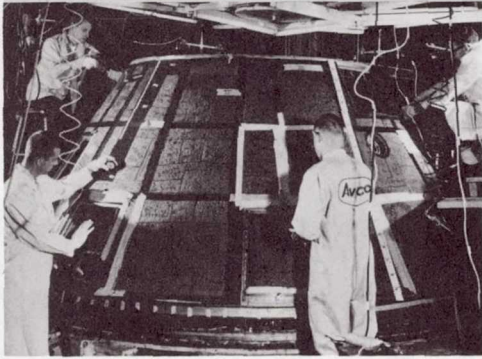
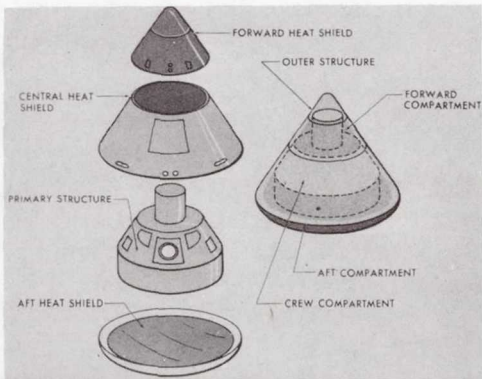
Houston remained strong, providing another source to draw on for help. Shortly after the move to Houston, Axel T. Mattson came to Texas as full-time liaison officer, coordinating the use of Langley's five-meter transonic wind tunnel in testing and studying the aerodynamic effects of reaction control jets and escape tower exhaust plumes on the command and service modules.

Langley's wind-tunnel experts also conducted diagnostic tests of heat transfer, heating loads and rates, and aerodynamic and hydrodynamic stability on the command module heatshield. The heatshield contractor—the Avco Corporation's Everett, Massachusetts, division—had proposed an ablative tile shield, a layered and bonded single-piece construction similar to that used on Mercury. Then McDonnell had advanced heat protection technology by developing ablator-filled honeycomb material for Gemini. When North American and NASA engineers approved this thermal protection Avco refined the new system to withstand the higher heating rates of lunar reentry. McDonnell's Gemini heatshield was made of a Fiberglas honeycomb material; the ablator, developed by Dow-Corning, was poured into it and allowed to harden. The Apollo ablative heatshield, however, was bonded to an inner brazed stainless steel honeycomb shield, and the 400 000 honeycomb cells in its plastic outer shield were filled by hand using a caulking gun,²⁰ with an ablator developed by Avco.

While the heatshield was going through its growing pains, the earth landing system for the command module was beginning to mature. Apollo's preliminary plan had included either water or land landing. John W. Kiker, a landing system specialist in Houston, had studied several alternatives: a rotating wing (like a helicopter's), a flexible wing (similar to a paraglider), or traditional parachutes (such as were used in Mercury). Kiker, working with experts at Langley and Ames, ran the proposed models through wind-tunnel tests and then asked the Flight Research Center to put the equipment through free-flight tests at Edwards Air Force Base.²¹

But by the middle of 1962 hopes for a touchdown on land were beginning to fade. At a meeting in Houston on 10 May engineers of Northrop-Ventura (the recovery system subcontractor) described their designs for a cluster of three ring-sail parachutes for the main landing system. North American liked Northrop's proposal better than the system being tested, which deployed the parachutes through the heatshield cover on the conical top of the command module. In the proposed system, the cover would be jettisoned before the parachutes were released. On 16 May Houston told North American to go ahead with the development of this multiple-parachute system and to set the paraglider aside for further review.²²

At that time, North American was developing a paraglider landing system for the Gemini spacecraft. In Houston, Max Faget noted that the contractor was having trouble with the Gemini system and became skeptical of the paraglider's value for Apollo. In June 1962, he recommended water



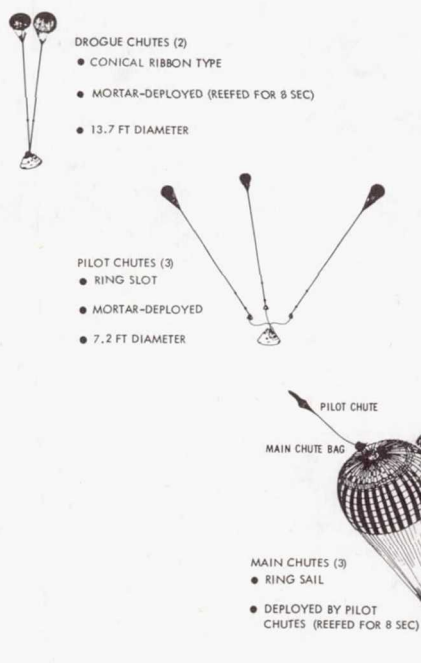
The drawing outlines major parts of the command module structure. In the photo at top right, the cabin section (or primary structure) of the CM is assembled at North American in 1965. Technicians (in the center left photo) work on the central heatshield, the two men on the sides applying heat-protection ablative material with caulking guns. A completed central heatshield in the bottom right photo is lowered into place over the primary structure in May 1966. In the bottom left photo, technicians prepare aft heatshields to attach to model CMs. These shields were made of fiberglass for test vehicles that did not require heat protection; the finished versions were of the same materials as the central heatshield.

CHARIOTS FOR APOLLO

landings for the lunar program. At NASA Headquarters, George Low told Brainerd Holmes that North American's concentration on parachutes for Apollo would mean the end of the paraglider for that program. Holmes wanted to know if it could be put in later, provided the technical difficulties were solved. Low said this could be done only if the paraglider were ready within a year.²³ When NASA and the Navy recovered John Glenn and Scott Carpenter and their Mercury spacecraft from the water with comparative ease, chances for a dry landing in Apollo grew slim.

Another key part of the command module that had to keep moving was the guidance and navigation system. To get started in the right direction, representatives from North American and MIT decided to meet regularly, either at Downey or Cambridge, to keep an eye on progress and trade information. In early 1962, the guidance and navigation system had, of course, moved very little beyond the embryo stage. Some advances had been made on the gyroscopes and accelerometers for the inertial measurement unit (similar to that used to help guide the Polaris missile), but digital computer development and the space sextant were not well defined.²⁴

Manned Spacecraft Center engineers had questioned whether an astronaut in a pressurized suit could operate a sextant or the other delicate pieces of navigation equipment. The Apollo contract had specified a shirt-sleeve environment. For this reason, North American had been told not to include in its design a hatch that opened by explosives, like Mercury's. An accidentally blown hatch would cause an instant vacuum and certain death for a crewman not wearing his pressure suit. But on some occasions, such



Parachute recovery system

MATCHING MODULES AND MISSIONS

as launch, the crew would be in their suits and would need equipment that could be operated while wearing the bulky gloves and helmet.²⁵

In June 1962, several Manned Spacecraft Center and North American engineers went to MIT to learn how the crew was to operate the guidance system. One of the talks covered the use of the sextant in determining navigational position. At that point, the MIT experts were invited to Houston to try operating the sextant while wearing an inflated suit. Whether they came was not documented, but in the succeeding months modifications made the sextant and suit operation more compatible. The chief result of all these meetings, however, was a new understanding of the command module's cabin layout, which gave MIT a clearer picture of how components should fit.²⁶

Ames Research Center engineers also participated in the meetings (giving Gilruth another set of specialists to call upon in monitoring MIT's work). The Ames guidance experts sponsored a session at a NASA-university conference that dealt with such subjects as midcourse guidance and navigation techniques and the procedures for reducing the uncertainties connected with these operations. Ames speakers recommended making midcourse corrections early in flight to avoid the wider dispersions and greater fuel use that might result from making trajectory changes closer to the moon. Studies by Ames on atmospheric entry guidance—another critical operation—indicated that a man could indeed steer his spacecraft through the narrow reentry corridor to a safe landing on the earth.²⁷

When some components of the command module's guidance and navigation system were ready for development and fabrication by subcontractors, NASA Associate Administrator Robert Seamans appointed a Source Evaluation Board in January 1962, headed by Robert G. Chilton,* of MSC, to select industrial supporters for MIT. NASA chose the AC Spark Plug Division of General Motors to build the inertial platform, Raytheon to make the digital computer, and the Kollsman Instrument Corporation to manufacture the optical systems. By May 1962, most of these contractual arrangements were complete.²⁸

NASA's top officials had been concerned about MIT's ability to build a guidance and navigation system that would take a crew to the moon and back to the earth. As the system began to take shape, another worry cropped up. Would the Instrumentation Laboratory be able to manage the industrial contractors once the design evolved into development? To be certain that the subcontractors understood the arrangement, Seamans visited the Wakefield Laboratory of AC Spark Plug in July, where he was assured that AC and MIT could work together just as they had on the Titan II inertial

* Chilton's board members were Caldwell C. Johnson, Jr., Charles F. Bingman, Arthur E. Garrison, and Carl D. Sword of MSC; Richard C. Henry and Earl E. McGinty of NASA Headquarters; Merrill H. Mead of Ames; and two nonvoting participants, Ralph Ragan of MIT and James T. Kopenhagen of NASA Headquarters.

CHARIOTS FOR APOLLO

guidance system. But the managerial task in the complex and interlocking systems of the command module, as well as those of the other vehicles in the Apollo stack, had to be spelled out in precise and formal guidelines to ensure orderly progress. A system of "Interface Control Documents" became standard.

There was nothing very mysterious about the Interface Control Documents. Somewhere along the line, some piece of Apollo's two million functional parts assembled in one place had to meet and match with a piece put together in another place. After MIT had designed and supervised the building of the guidance and navigation system, for example, the component was sent to North American for installation in the command module. Size and location of the equipment had to be defined and agreed upon in advance so it would fit properly. Because of the many, many companies working on the different parts of the Apollo stack, these interface documents were essential in laying out just where and how the parts would come together—systems with spacecraft, spacecraft with launch vehicles, launch vehicles and spacecraft with launch facilities, and all these systems and craft with the crew and with launch and mission control centers.²⁹

All in all, during 1962 good progress had been made in getting command module development under way. Contractors were working together, and cooperation among the NASA field centers had improved. One of the underlying factors in this advancement had been the establishment of a formal Apollo spacecraft management office at the Manned Spacecraft Center.

In January 1962, when Charles Frick became manager of the new Apollo Spacecraft Project Office, he assumed responsibility "for the technical direction of North American Aviation and other industrial contractors assigned work on the Apollo Spacecraft Project." Frick arrived at Langley Field, Virginia, just in time to meet the 45 persons that his deputy, Robert Piland, had gathered into the new project office before they moved to Houston on 1 February. The new organization settled into the Rich Building, one of the center's 13 rented sites scattered around the Gulf Freeway.³⁰ But, even before Frick's arrival and the establishment of the formal spacecraft office, the Apollo workers in Gilruth's center had taken on an expanded responsibility.

PRELIMINARY DESIGNS FOR THE LUNAR LANDER

Work at NASA's lead Apollo center on the excursion vehicle had started in late 1961, when designers began looking at the advantages of lunar-orbit rendezvous. But these had been analyses of general rather than specific configurations. Wernher von Braun's researchers in Huntsville had

MATCHING MODULES AND MISSIONS

also studied concepts for soft-landing. For landers weighing several thousand kilograms (and thus presumably manned), they considered liquid-fueled engines more practical than those using solid propellants. Houston engineers also drew on studies conducted by the Langley Research Center in Virginia. By mid-September 1961, Gilruth's people had roughly worked out a mission plan and figured out the kind of vehicle that might do the job. From September to December, they tried to nail down systems operations more precisely, particularly in such areas as propulsion and communications.³¹

The mysterious nature of the moon's surface received much attention, since a safe lunar landing presented some tricky design problems. Manned Spacecraft Center engineers considered such things as the effect of engine exhaust on the surface layer, the influence of dust layers on landing-gear footpads, and surface dust effects on optical and radar landing aids. Although a model of the lunar surface drawn from the best available data was used for these engineering studies, Gilruth's men realized that there were varying views among scientists about the lunar surface characteristics, especially the depth of the dust layer.³²

By early 1962, spacecraft specialists had begun to move beyond the study phase. While others fought for their chosen mode, they worked out details for building the lunar module and started preparing for its procurement. The newly created Houston Apollo spacecraft office drafted a lengthy document in April defending the hardware and operational feasibility of lunar rendezvous and the excursion vehicle. Basic concepts of the mission profile and docking and of storage arrangements for the lander inside the spacecraft adapter were fairly firm. Many aspects of guidance and navigation and of operations in lunar orbit were well understood. Several theoretical vehicle shapes were depicted, velocity requirements were delineated, vehicle weights (up to 9200 kilograms, including a 25-percent contingency margin) were estimated, and mission development plans, using the Little Joe II and the Saturn C-1B and C-5, were considered.³³

William Rector was assigned to Frick's project office staff "to start worrying about the LEM." Using command module documentation as a guide, he wrote a work statement. Rector drew on technical expertise from within the project office and from other center organizations, particularly Max Faget's research and development directorate. He relied heavily on advice from the Spacecraft Research Division in preparing the procurement documents. Rector began with "a real shoestring operation," a small group of specialists for communications, propulsion, and overall configuration, and for assembling information and writing the request for proposals.

Early in May, Rector and his team finished the preliminary statement of work and started on the formal proposal request. "I'll never forget," he said later, "all we did was just sort of turn the command module upside down and put a window and a propulsion stage in it." From this point

CHARIOTS FOR APOLLO

on Rector and his group continually revised the proposal, to include additional information on visibility requirements, crew location, and propulsion systems as it became available. They also took first cuts at the guidance and communications systems, among others, trying to work out the basic interrelationships for each subsystem and to get them into the work statement.³⁴

The spacecraft office wanted the work statement in its final form by mid-July. When the early drafts went to Washington for review, Joseph Shea in the Office of Manned Space Flight insisted that the vehicle should be configured for unmanned, as well as manned, flight because NASA might want to use it to ferry large payloads to the lunar surface. Everyone in Houston, from Gilruth on down, claimed that such a lander would be unreliable. The lunar module design should not be compromised by throwing in this dual requirement.

After a series of meetings, including a last-minute session with Gilruth and Frick, Rector carried a work statement to Headquarters that left the door open for future negotiations. To avoid further delay in procurement, he had inserted a clause that obligated the contractor to study the advantages and drawbacks of automatic versus manned modes and to assist the agency in coming to a final decision. The procurement documents were approved and issued to 11 aerospace firms* during the latter half of July.³⁵

While Houston was getting ready to procure the lander, Shea's Office of Systems was defending the agency's choice of lunar-orbit rendezvous before the President's advisers and the public. This was a time-consuming and harried process, a grinding day-by-day burden, that began even before the official announcement in July.

PRESSURES BY PSAC

The Space Vehicle Panel of the President's Science Advisory Committee (PSAC) was apprehensive about lunar-orbit rendezvous well before NASA picked that approach. After the decision was made public in July 1962, Nicholas Golovin, at the behest of Jerome Wiesner, probed deeply into NASA's planning activities. If NASA was to reverse its decision, pressure would have to be applied before the development contract was awarded. Once that had been done, the course of Apollo would be virtually impossible to change.

PSAC's interest in manned space flight had begun with the Mercury program and had led to the establishment of the Space Vehicle Panel in the fall of 1961. Headed by Franklin A. Long of Cornell University, the panel

* Companies invited to submit proposals were Lockheed, Boeing, Ling-Temco-Vought, Northrop, Grumman, Douglas, General Dynamics, Republic Aviation, Martin-Marietta, North American, and McDonnell.

MATCHING MODULES AND MISSIONS

had met in October and December for briefings by NASA officials on the agency's plans for launch vehicles. Long reported in January 1962 the group's observations and recommendations for strengthening the country's booster capabilities. Since Apollo planning had by then shifted from direct flight to earth-orbit rendezvous, the panel also pressed for the development of rendezvous and docking techniques.³⁶

Thus, 1961 had closed with some degree of harmony between NASA and PSAC; but that soon changed. As the space agency began to waver on its mode choice during the first half of 1962, Wiesner, Golovin, and the panel wedged themselves into the daily activities of spacecraft development. When NASA began to look more favorably on lunar rendezvous, relations between the two organizations deteriorated rapidly.

Panel members visited Los Angeles during February for discussions on spacecraft and launch vehicle development by North American and then went on to Washington and several of the NASA centers later, looking closely at the mode comparison studies then in progress. They grew resentful of NASA's refusal to supply them with every draft document, both government and industry, the agency had on the subject. NASA, on the other hand, chafed at the panel's snooping into internal and contractual relationships, insisting that these activities lay outside PSAC's advisory authority.³⁷

During May and June, Golovin asked for detailed information on launch vehicles and spacecraft for all approaches under consideration; he also requested progress reports from all Apollo spacecraft contractors and on engine development programs. Shea did not want to release this material while the mode comparison studies were in progress, and he sent a staff member to tell Golovin that schedules were not firm and that his request was premature. Golovin was, as a matter of fact, at something of a personal disadvantage in his pursuit of NASA information. He had stirred up controversy during the 1960-1961 period of Project Mercury with his statistical reliability analysis methods, which many Mercury engineers considered merely a "numbers game."³⁸

Just before the lunar rendezvous selection was publicly endorsed, the Space Vehicle Panel met with NASA officials in Washington on 5 and 6 July. In preparation for this meeting, Golovin again asked Shea for the draft documents that had been used to produce the mode comparison studies. Shea advised Golovin that this material was still subject to final editing. Golovin said that all the panel wanted was a preview of the technical data and analyses of various mode alternatives, their feasibility, and advantages.

On 3 July, after examining some papers Shea had sent the day before, Wiesner and Golovin thought they had found a flaw. One table showed a higher probability of disaster for lunar rendezvous than for either earth rendezvous or direct flight. Wiesner called Webb, who, in turn, telephoned Shea and suggested that he see Wiesner immediately.

CHARIOTS FOR APOLLO

Shea tried to persuade Wiesner and Golovin that the reliability numbers based on Marshall's computations contained an error. The PSAC officials were also told that figures from the report of the Large Launch Vehicle Planning Group (of which Golovin himself had been chairman) were invalid because of unduly pessimistic assumptions about the reliability of rendezvous and the difficulties of abort. Calculations made within the Office of Manned Space Flight, Shea argued, showed success-failure probabilities essentially the same for all three modes. Shea got nowhere with his assertions, and he left the meeting discouraged. But he was still hopeful that the forthcoming session with the space panel would "allow us to get the facts squared away."³⁹

At the 5-6 July assembly, Shea's hopes for clearing the air were dashed when panel member Lester Lees distributed a memorandum presaging the adverse tone of the panel's final report, to be issued later that month. (Lees, from the California Institute of Technology's Guggenheim Aeronautical Laboratory, was a paid consultant to North American, which did not favor lunar rendezvous. Shea was convinced that this was the reason for his antagonism to lunar-orbit rendezvous.) Lees agreed that all four mission modes were technically feasible. But, he asked, "which of these risky adventures involves the least risk to the astronauts, provides the greatest growth potential for the manned space program, and at the same time gives us the best chance of fulfilling the President's [goal] to land an American on the moon by 1970?" Lees recommended earth-orbit rendezvous with the Saturn C-5 as the prime mode and direct flight using an uprated C-5 as backup. He disputed NASA's claims that the lighter, more maneuverable landing craft was significantly better than the command module for being set down on the moon. Lees also discounted NASA's demands for extensive visibility for the hover and touchdown maneuver, which was looked on by some pilots, he said, as "probably similar . . . to landing 'on instruments' here on Earth."⁴⁰

The Space Vehicle Panel's reservations about lunar-orbit rendezvous were reemphasized by Wiesner in Webb's office on 6 July. Shea, Brainerd Holmes, and Robert Seamans listened as Webb was forced to equivocate, to agree that the lunar rendezvous decision was only tentative. Later in the year, following additional mode studies, NASA would either reaffirm its July preference or pick one of PSAC's favored approaches.⁴¹

During the last half of July, the formal positions of the two sides were staked out. On the 17th Wiesner wrote to Webb spelling out PSAC's opinions of NASA's manned programs, particularly lunar rendezvous in relation to booster capabilities and America's military posture in space. Wiesner accused NASA of not adequately assessing such hazards as radiation and the potential problems of weightlessness. He had, Wiesner told Webb, "assured [President Kennedy] that there is ample time to make the

MATCHING MODULES AND MISSIONS

additional studies . . . agreed upon before the contracts for the lunar landing vehicle need be awarded."

Webb assured Wiesner that NASA was, and had been, investigating weightlessness and radiation. The Administrator defended lunar rendezvous as a contribution to American space capabilities: "It is our considered opinion," Webb wrote, "that the LOR mode . . . provides as comprehensive a base of knowledge and experience for application to other possible space programs, either military or civilian, as either the EOR mode or the C-5 direct mode."⁴²

The PSAC panel issued its final report on 26 July, still contesting NASA's justification for lunar rendezvous and affirming once again the desirability of two-man direct flight. "We can only note that the Panel was originally widely divided in its opinions, but that after hearing and discussing the evidence presented to us, there is no dissent in the Panel to the views presented here."⁴³

Thus, in July, President Kennedy found the space agency and his scientific advisory body firmly entrenched in separate camps. The situation remained static until lunar module procurement activities accelerated. Then Wiesner and his panel tried once more to block lunar rendezvous.

Golovin knew that the Manned Spacecraft Center was getting ready to let the lander contract. In mid-July, he asked NASA to arrange a briefing at Downey so he could review the technical details of North American's studies of direct and rendezvous mission modes. Most North American officials favored almost any mode except lunar-orbit rendezvous, which kept the command module from actually landing on the moon. A humorous cartoon on the company walls during August 1962 depicted a rather bored and disgruntled man-in-the-moon eyeing an approaching command module with lander attached. The caption read, "Don't bug me, man." Golovin, hoping for a negative response from these contractor studies, insisted that NASA allow the briefing. Webb complained to Wiesner that NASA "had rather complex relationships with North American" and "did not want a disturbing influence brought to bear." When Wiesner offered to withdraw the request for the visit, however, Webb declined, saying he just wanted to be sure that Wiesner was aware of his concerns.

Golovin had his California briefing at the end of July. On the way back to Washington, he stopped off at Cleveland to see what the Lewis Research Center was doing on the mission mode comparisons. Associate Director Bruce Lundin told Golovin that if he wanted this kind of information he should ask NASA Headquarters for it.⁴⁴

In August, Wiesner told Webb of the Space Panel's conviction that NASA had not selected lunar-orbit rendezvous because of any overriding technical reasons and had not satisfactorily justified its decision to PSAC. The Administrator admitted that he saw "some real value [in having

CHARIOTS FOR APOLLO

PSAC's] independent judgment," but added, "we [are] an operating agency and [can] not submit . . . our decisions for this independent judgment." Webb said that NASA "would have to find some [other] method of review that [can] not prevent [our] moving ahead." Wiesner conceded that "it was . . . important to keep in motion."⁴⁵ Tacitly, then, he acknowledged the priority of President Kennedy's deadline.

But Wiesner and Golovin still did not stop their sorties. Golovin visited Shea on 22 August to suggest that NASA invite a number of independent experts to decide who was right on the mode question. Shea responded that NASA was already using outside help. This session with Golovin "reinforced [Shea's] feeling that we are in for another go-around with the PSAC Committee." He was certain that Golovin and Wiesner still believed that they could overturn the mode decision.⁴⁶

The Webb-Wiesner and Shea-Golovin discussions had, if anything, widened the gap between NASA and PSAC. Early in September, Wiesner again wrote Webb, reiterating his concerns about lunar-orbit rendezvous and this nation's inferiority to Russia in the big booster field. PSAC, he assured Webb, stood ready to assist NASA in gathering "the best talents nationally available" to study the mode question. Wiesner sent a copy of this letter to the President, perhaps hoping that Kennedy might step in to settle their differences.⁴⁷

President Kennedy did, in fact, become involved while on a two-day visit to NASA's space facilities on 11 and 12 September 1962. After viewing the Apollo spaceport being built in Florida, Kennedy flew on to Huntsville, Alabama. There, during a tour of Marshall and a briefing on the Saturn V and the lunar-rendezvous mission by von Braun, Wiesner interrupted the Marshall director in front of reporters, saying, "No, that's no good." Webb immediately defended von Braun and lunar-orbit rendezvous. The adversaries engaged in a heated exchange until Kennedy stopped them, stating that the matter was still subject to final review. But what had been a private disagreement had become public knowledge. Editorial criticism stemming from the confrontation—including the question, "Is our technology sound?"—forced NASA to justify its selection of lunar-orbit rendezvous to the public, as well as to PSAC.⁴⁸

Accusations by Wiesner that lunar rendezvous had not been thoroughly studied particularly galled Shea. He compiled material for Webb to use in refuting this charge, outlining the many studies leading to the selection. Shea estimated that more than 700 scientists and engineers at Headquarters, at the field centers, and among contractors had spent a million man-hours working on the route comparisons.⁴⁹

In early August, Shea formed a team to monitor contracts awarded to Space Technology Laboratories and McDonnell to rehash the feasibility of a direct flight by two men in either a scaled-down Apollo or a modified Gemini spacecraft. Gilruth worried that these studies might impede Mc-

MATCHING MODULES AND MISSIONS

Donnell's work on Gemini, especially after a NASA visitor reported that the St. Louis contractor apparently wanted to expand the scope of the study as much as NASA would allow.

Shea and his staff reviewed these studies and presented the results to the rest of the manned space flight organization early in October. The contractors agreed that either two-man direct flight or earth-orbit rendezvous was feasible but both were less attractive than lunar rendezvous because the probability for mission success was lower, the first landing would be later, and the developmental complexity would be greater. The vote was still for three-man, lunar-orbit rendezvous.⁵⁰

Among the strongest criticisms of the PSAC-preferred two-man direct flights was an analysis that indicated they would be marginally feasible with cryogenic propellants in the braking stages and with storable propellants for the lunar takeoff and return to earth. Such flights were clearly possible only if cryogenics were used on the return leg as well. But Houston was unalterably opposed to cryogenics, which required complicated equipment and special handling, for the lunar takeoff stage.

Another indictment of PSAC's choice was that the panel members persisted in claiming that lunar rendezvous had no time advantage over the other modes. NASA was equally obdurate in its belief that adopting one of the other modes would mean a lag of ten months. A space tanker would have to be developed, critical refueling techniques would have to be perfected, and changes in the S-IVB stage would have to be made to permit long-term storage of cryogenic propellants. All of this would mean more money, perhaps as much as an additional \$3 billion.⁵¹

The Office of Manned Space Flight assembled the meat of these studies into another "final" version of the mode comparison, which was issued on 24 October 1962. Earlier arguments for lunar rendezvous, the report stated, were as valid in October as they had been in July. That approach was still "the best opportunity of meeting the U.S. goal of manned lunar landing within this decade."⁵²

The day NASA released this report, Webb wrote Wiesner that, unless the science adviser had objections serious enough to be taken to the White House for arbitration, a contract would be awarded for development of the lunar excursion module. He told Wiesner:

My understanding is that you . . . and your staff . . . will examine this and that you will let me know your views as to whether we should ask for an appointment with the President.

My own view is that we should proceed with the lunar orbit plan, should announce our selection of the contractor for the lunar excursion vehicle, and should play the whole thing in a low key. . . .

CHARIOTS FOR APOLLO

If you agree, I would like to get before you any facts, over and above the report, perhaps in a thorough briefing, which you believe you should have in order to put me in [a] position to advise Mr. [Kenneth] O'Donnell [one of the President's aides] that [you do not wish] to interpose a formal objection. . . . In that case, I believe Mr. O'Donnell will not feel it wise to schedule the President's time and that the President will confirm this judgment.⁵³

Wiesner and Golovin were not reconciled by NASA's latest justification. Upon reviewing the report, Wiesner asked Holmes for material to expand on that abstracted from the proposals of those aerospace companies responding to the request for bids to develop the lunar lander. Not too surprisingly, the bidders had all emphasized the advantages of a lunar excursion vehicle and had played down the difficulty of rendezvous as an added operational step. All the proposals cited the benefits from lunar rendezvous, chiefly mission success and crew safety, with a craft specifically designed for lunar landing and the need for only one Saturn C-5.

Wiesner now wanted to examine these contractor documents in full, which Webb refused to allow because of the proprietary information they contained. Next, Wiesner asked that certain material be given Golovin without identification of the contractors. What the pair was seeking, Webb confided to Seamans, were the lunar weight estimates, but "I cannot see how the contractors' estimates can help [them] decide whether you, I, and Dryden have made the correct decision."⁵⁴

Holmes did send Wiesner those sections of the proposals that dealt with estimated weights for the lander. Most of the figures assumed a target weight of around 10 000 kilograms. But, Holmes pointed out, estimates of the different subsystems had varied widely. More knowledge of the lunar surface and of radiation and meteoroid fluxes would probably "force weight increases in the landing gear and shields." Both Mercury and Gemini had demonstrated the need for keeping a margin of weight for additional equipment and redundancy, Holmes added.⁵⁵

On 2 November, Wiesner and Golovin met with Webb and his staff once again. It was obvious that the two organizations still occupied opposing camps. Golovin presented a detailed re-analysis of the 24 October mode study, challenging both payload margins and reliability and safety considerations. He still contended that, of the two modes capable of using only storable propellants, earth-orbit rendezvous had a somewhat higher performance margin. Moreover, with cryogenic propellants in the landing stage (and for this he cited research done at Lewis), two-man direct flight was quite feasible.

But Golovin found more serious faults in NASA's stance on reliability and crew safety. As he wrote Shea later that day, "It has been surprising to [read in the report] that the Direct Ascent case is less likely to be successful,

MATCHING MODULES AND MISSIONS

and to be more dangerous to the crew than the obviously more complicated LOR mode.”⁵⁶

Members of Shea's staff disputed Golovin's estimates of performance margins and reliability factors that made earth-orbit rendezvous and direct flight appear safer than lunar rendezvous. This exchange—NASA's final technical response to outside criticism of the agency's handling of the mode question—was actually a postmortem. After Webb's letter of 24 October, Wiesner decided not to take his objections to Kennedy, since the President was occupied with the Cuban missile crisis. (Subsequently, Wiesner took the position that had the situation been different, his actions might not have been the same.) Webb then advised the White House that Apollo was committed to lunar rendezvous.⁵⁷

Wiesner had never argued that this mode was impossible; he had simply preferred other methods. He realized the depth of Webb's commitment to his technical organization. If Wiesner had carried the question to President Kennedy, Webb would have insisted that NASA alone must make crucial program decisions. The Chief Executive almost certainly would have backed the man he had appointed to run NASA. So, presumably, Wiesner decided to let the issue die. At the end of the first week in November 1962, NASA announced its selection of a manufacturer for the lunar module.⁵⁸

FITTING THE LUNAR MODULE INTO APOLLO

Since responsibility for the Apollo command and service modules already rested with Gilruth's Manned Spacecraft Center, NASA assigned Houston to procure and manage the lunar excursion vehicle. NASA officials decided to hire a separate contractor to develop the lunar landing spacecraft.

North American had made a strong bid for the lander when the lunar travel mode became a hot issue. Although the company was sent a request for proposals in July 1962, it was first discouraged, and then precluded, from bidding on this contract. NASA evidently believed that North American already had all the Apollo development work it could handle.⁵⁹

Facing the loss of the glamor associated with landing its own craft on the moon, North American did not give up gracefully. Harrison Storms carried his case to Administrator Webb, suggesting that his company be selected as sole source contractor for the lander, farming out most of the actual hardware work. This arrangement would have made North American the systems manager, responsible for integrating all the payload vehicles. Legal and procurement officers within NASA warned Webb against this approach. The agency should contract the lander directly, they urged. To permit an industrial firm to take over this task without competition, even

CHARIOTS FOR APOLLO

though NASA would have the final approval of the selection of the subcontractors, "might be regarded as a delegation of NASA's inherent responsibility to perform its procurement function."⁶⁰

Requests for proposals on the lander were issued on 25 July 1962, and a bidders' briefing was held in Houston on 2 August. On 5 September, barely five weeks after the issuance, NASA announced that nine companies had submitted proposals and that the agency planned to award the contract in six to eight weeks. Of the 11 companies originally invited to bid, only McDonnell—and North American—had not submitted proposals.

Evaluations began at Houston immediately after the proposals were received and they ended on 28 September. At Ellington Air Force Base in mid-September, company officials made formal presentations to the Source Evaluation Board and a number of technical management panels. NASA teams then made one-day visits to the company plants, to see what facilities each bidder could draw upon to support the development program.⁶¹ Early in October, officials from Houston presented their findings and recommendations to NASA Headquarters. Holmes wanted the selection completed, approved, and announced by the middle of the month. But the last-minute demands by PSAC postponed the contract award for three weeks. On 7 November, NASA formally announced that the Grumman Aircraft Engineering Corporation of Bethpage, New York, would build the excursion module.⁶²

Several bidders had been very close, both technically and managerially, William Rector later said. Any of them could have done the job—"Grumman didn't turn in the only good design." A major factor in Grumman's selection had been its facilities: spacious engineering design and office accommodations, ample manufacturing space, and a clean-room complex for vehicle assembly and testing.

The Manned Spacecraft Center continued its studies, even after the requests had been issued. Rector remembered that "our designs were really beginning to take shape. . . . We were getting a much better feel for what we wanted this thing to look like." The Apollo Spacecraft Project Office had been realigned on 1 August, to give the lunar module an organization of its own. Rector became project officer for the lander and Thomas Markley for the command and service modules. Rector and Markley then revised the North American statement of work to reflect Grumman's and the lunar module's place in the Apollo-Saturn stack, particularly in the arrangements for docking and for stowage within a protective adapter section.

Rector's office began defining the lander's subsystems: propulsion, guidance and control, reaction control, electrical power, and instrumentation. The planners hoped to use Mercury and Gemini spacecraft components as well as Apollo command and service module parts ("common usage" equipment) in the new vehicle. The guidance and navigation system in the command module received the closest initial scrutiny for common usage parts. MIT studies indicated that the inertial measurement unit, the

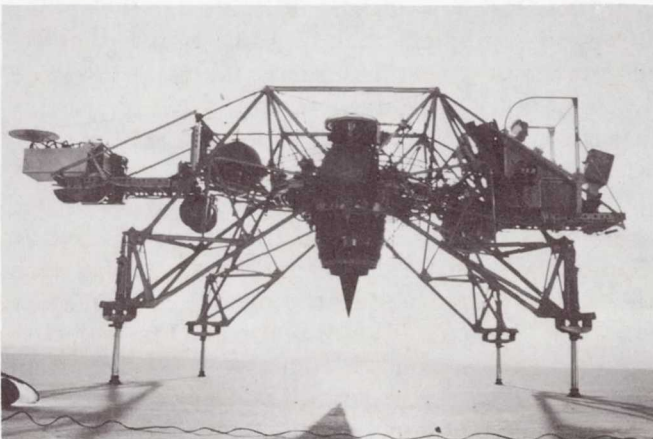
MATCHING MODULES AND MISSIONS

telescope, and some computers and displays might be modified for the lander.⁶³

Numerous lunar-module-related design problems were examined during the last weeks of 1962. Among the most pressing were requirements for rendezvous and landing radar (and where to put the equipment); analyses of individual vehicle systems, such as electrical power and thermal control; considerations of mission trajectory from lunar orbit and back and of abort trajectories from any point during the descent; projections of overall costs for developing the vehicle; and questions of dust layers on the moon, the blast effect caused by descent engine exhaust, and the influence of these factors on both vehicle design and landing site selection. During this time, NASA decided that the lander's propulsion systems would be tested at White Sands in facilities similar to those being developed at Sacramento for testing the service module's main engine.⁶⁴ Apollo leaders also expected to flight-test the lunar module in New Mexico, using the Little Joe II booster.

Simulating lunar landings to train the crews would require ingenuity; imitating one-sixth g within the earth's gravitational field is complex and difficult. Three methods were considered, the simplest being a fixed-base simulator like those built for the Mercury and Gemini programs. More complicated were plans for tethered flights of a model of the lunar lander at Langley on a huge A-frame structure that used cables and rigging to relieve the descent engine of most of the vehicle's weight.

The third method, which would simulate in free flight the actual landing on the moon, employed a unique and specially fitted flying machine called the lunar landing research vehicle. Dubbed the "flying bedstead" or "pipe rack," this was a complex combination of rocket motors and a vertical jet engine designed to accustom the astronauts to flying in the lower gravity of the moon. Work on the vehicle, based on concepts proposed by Bell Aerosystems, had already begun at NASA's Flight Research Center at Edwards Air Force Base in California. After awarding a contract to Bell in



The Bell Aerospace lunar landing research vehicle, manufactured for NASA as a trainer for the moon landing, was frequently referred to by the news media and others as the "flying bedstead."

CHARIOTS FOR APOLLO

January 1962, that center solicited support from Houston in designing, building, and flying the craft. Paul F. Bikle, Director of the Flight Research Center, insisted that close contact with the builders of the lunar module during the designing of the hover craft was essential to make certain the handling characteristics of the moon lander were accurately represented.⁶⁵

NASA ADJUSTMENTS FOR APOLLO

In mid-1962, Washington program planners spelled out in detail the interrelations of Apollo and the total space program. The agency's unmanned satellites and space probes, especially Ranger and Surveyor, would have to focus on the lunar mission, since the most pressing need was for accurate information about the space environment (such as meteoroid and radiation hazards) and the lunar surface.⁶⁶ Subordination of unmanned scientific programs to the manned programs brought considerable criticism during the next few years.

NASA leadership was confronted during the summer and fall of 1962 with the dual tasks of informing Congress of the status of Apollo and of fitting its fiscal plans to the lunar-rendezvous approach. Defending Apollo's budget request for fiscal 1963 before the Senate Committee on Appropriations on 10 August 1962, Webb and Low reiterated that technical considerations had been important in choosing that approach, but so had costs. Lunar rendezvous for Apollo, although not lessening the agency's needs for the upcoming year, would be cheaper in the long run. But NASA must get started on both the lunar vehicle and a C-1B version of the Saturn booster, Webb pointed out, to develop and test rendezvous procedures in earth orbit before attempting them in lunar orbit.⁶⁷

In late 1962 and early 1963, financial resources for NASA were uncertain, particularly the funds needed for development of the lunar module. Houston needed to know when the money would be available. On 9 October, Holmes asked Seamans to request a supplemental appropriation from Congress, but Seamans refused. For the next year and a half, the fiscal 1963 and 1964 funds, set at \$2.058 billion and \$3.402 billion, would cover research and development and construction of facilities. This should be enough, Seamans said, to keep on schedule and meet a 1967 landing date.⁶⁸

On 21 November 1962, Webb, Holmes, and others met with the President to explore the possibility of an Apollo landing earlier than 1967 and to discuss NASA's budget. Kennedy asked the Administrator for a policy statement on the priority of the moon landing within the overall civilian space effort. On 30 November, in a lengthy letter, Webb replied: "The objective of our national space program is to become pre-eminent in all important aspects of this endeavor and to conduct the program in such a manner that our emerging scientific, technological, and operational competence in space

MATCHING MODULES AND MISSIONS

is clearly evident." Apollo, the largest single project within NASA, consuming three-fourths of the agency's resources, was "being executed with the utmost urgency" and was expected to "provide a clear demonstration to the world of our accomplishments in space."

Although it had the highest priority within NASA, the manned lunar landing program alone would not achieve superiority in space, Webb continued. "We [must] pursue an adequate well-balanced space program in all areas. . . ." He advised against canceling or curtailing space science and technology development programs merely to funnel these funds to Apollo, although that money, some \$400 million, was just the additional amount needed by Apollo for 1963. NASA's top officials were concerned, he said, that attempts to get a budget supplement might jeopardize appropriations for coming years and possibly leave the agency open to charges of cost overruns and poor management. "The funds already appropriated," Webb affirmed, "permit us to maintain a driving, vigorous program in the manned space flight area aimed at a target date of late 1967 for the lunar landing."⁶⁹

Although a steady flow of money during the succeeding years was essential to the success of Apollo, it was not the major concern in late 1962. The lunar module contractor had been selected, but there was still a lot of work to be done. And the lander was, potentially, the pacing item—the factor that would determine *when* the United States might land astronauts on the moon.

NASA-GRUMMAN NEGOTIATIONS

When Grumman was selected for Apollo, the company expanded from an aircraft producer into a major aerospace concern. This transition reflected a long-term resolution, and a considerable investment of funds, on the part of the firm's senior management to penetrate the American space market.

The story of Grumman's drive for a role in manned space flight has a rags-to-riches, Horatio Algerlike quality. The company had competed for every major NASA contract and, except for the unmanned Orbiting Astronomical Observatory satellite, had never finished in the money. Late in 1958, when NASA was looking for a contractor for the Mercury spacecraft, Grumman had tied with McDonnell in the competition. But only a short time before, the Navy had awarded several new aircraft development programs to Grumman. For almost three decades the words Grumman and carrier-based aircraft had been virtually synonymous. To avoid disrupting Navy scheduling and to ensure its contractor's concentration on Mercury, NASA had selected McDonnell.⁷⁰

Nevertheless, board chairman and company founder Leroy R. Grumman and president E. Clinton Towl had continued to support study pro-

CHARIOTS FOR APOLLO

grams to strengthen the firm's capabilities and build a cadre of experienced engineering experts. By 1960 Grumman's study group, guided principally by Thomas J. Kelly, had begun to focus on lunar flight, examining lunar spacecraft concepts and guidance and trajectory requirements. The company had also done some guidance work on circumlunar flight for the Navy and passed its findings on to NASA.⁷¹

When NASA awarded the three six-month Apollo feasibility contracts in the latter half of 1960, Grumman again bid unsuccessfully. But Kelly and about 50 engineers continued their investigations full-time, without monetary assistance from NASA. Through a series of informal briefings and reports, they kept the agency informed of what they were doing. This group, on one occasion, said that the lack of funds had limited its investigations to lunar-orbital flights. In mid-May, when the three funded feasibility contractors had submitted final reports, Grumman (like several other firms that had gone ahead independently) also presented the results of its study to the Manned Spacecraft Center.⁷²

Grumman officials had begun to realize just what a massive undertaking the Apollo program would be. After much soul searching, the company decided not to bid alone for the command module contract, joining with General Electric, Douglas, and Space Technology Laboratories in submitting a proposal. Grumman's chief contribution was cockpit design and layout. A strengthened space working group was now headed by Joseph G. Gavin, Jr., a Grumman vice president. On three floors of a commercial building near Independence Hall in Philadelphia, the teams, sometimes numbering 200 persons, from the four companies worked day and night to put its proposal together.⁷³

When NASA announced that North American had won the Apollo spacecraft contract, at the end of November 1961, the prevalent feeling at Grumman was, as one tired engineer recalled, "What do we do now?" One segment of the combined proposal, however, gave them some ideas and provided a reason to continue. The four firms had examined many aspects of a lunar landing mission beyond what was called for by NASA. One central feature the team explored was the mission mode, only lightly touched on in the proposal request. At the outset of work on the contract bid, each of the companies had studied a different mode. By chance, Grumman had drawn lunar-orbit rendezvous. After the studies had been compared, this approach was recommended in the joint proposal.⁷⁴ In the fall and winter of 1961-1962, Gavin turned full attention to lunar rendezvous and to the separate vehicle that would be needed.

Under the leadership of Gavin as Program Director and Robert S. Mullaney as Program Manager, the study group had achieved formal status in the corporate structure of Grumman and had acquired a number of Grumman's most experienced engineering and design experts. The team studied configurations of staged versus unstaged vehicles, subsystem require-

MATCHING MODULES AND MISSIONS

ments, propulsion needs, and weight tradeoffs for the lunar lander. Thus, when NASA issued the requests for proposals for the lunar module, Grumman was able to include a large amount of solid information in its bid. Even before lunar-orbit rendezvous had been chosen, Grumman had begun to build simulators, to define the facilities that would be needed for the program, and to construct the aerospace building where, in the beginning, all the design work was done.

Gavin and his people were confident that they were well founded in the technical requirements of the program; they also recognized that management capabilities would be an important criteria in the selection. They therefore enlisted a team of potential subcontractors and stressed the expertise of these allies. Prominent among the subcontractors were the firms for the two propulsion systems (Bell and Rocketdyne), which included the all-important throttleable descent engine.⁷⁵

Once Grumman had been selected, NASA agreed that a definitive contract could be written immediately, instead of (as with North American) an interim, or "letter," contract followed by interminable negotiations leading to final agreement. For the lunar module, Rector said, "we negotiated [the whole program], even though we didn't understand [it] that well at the time."

Grumman officials did not really know what NASA wanted. It was, in Kelly's words, "an example of ignorance in action, . . . at least on our part." Neither side fully appreciated the size of the development they were undertaking. The Grumman group entered negotiations under the impression that it was simply going to build the vehicle it had proposed, but "that wasn't what the NASA people had in mind." NASA expected that, once negotiations were concluded, Grumman would begin a preliminary design phase, redefining the complete spacecraft item by item. In the long run, the definition phase took longer than either party had anticipated. But Grumman had submitted a preliminary design of the lander, and "we were still somewhat enthralled with [it]," Gavin recalled. "It took some time for this to settle down."⁷⁶

Conferences between NASA and Grumman began on 19 November. About 80 persons from Grumman traveled to Houston for the talks. The Bethpage contingent was broken into a dozen technical teams and several program management, reliability, and support groups. Grumman's Negotiation Management Team comprised Gavin, Kelly, C. William Rathke (Engineering Manager), and John Snedeker (Business Manager). This management team obviously had more authority than North American's negotiating group had on the command and service modules, which was hardly surprising in view of Gavin's position as vice president of the company and director of Grumman's space activities.⁷⁷

The customer and contractor teams sat down to define contractual details, review subcontracting plans, work out a technical approach, and spell

CHARIOTS FOR APOLLO

out management arrangements and procedures for running the program. They examined requirements for facilities and determined the number and kinds of test articles (roughly equivalent to North American's boilerplate spacecraft), to avoid the need for building complete vehicles for testing specific subsystems. Agreements were eventually hammered out. The total value of the cost-plus-fixed-fee contract was set at \$385 million, including Grumman's fee of just over \$25 million.⁷⁸

Apollo officials had intended to finish the negotiations and sign the contract before adjourning, but the Grumman team caught the last available airline flight back to New York on Christmas Eve with a few details still unresolved. Gilruth went to Bethpage early in January to settle these outstanding items with Gavin and get the contract in final form for signing. The Houston center had also expected Headquarters approval during early January; that, too, was delayed. On 14 January 1963, NASA told Grumman to begin development of the lunar module, although the contract was not signed until early March, at a revised cost figure of \$387.9 million.⁷⁹

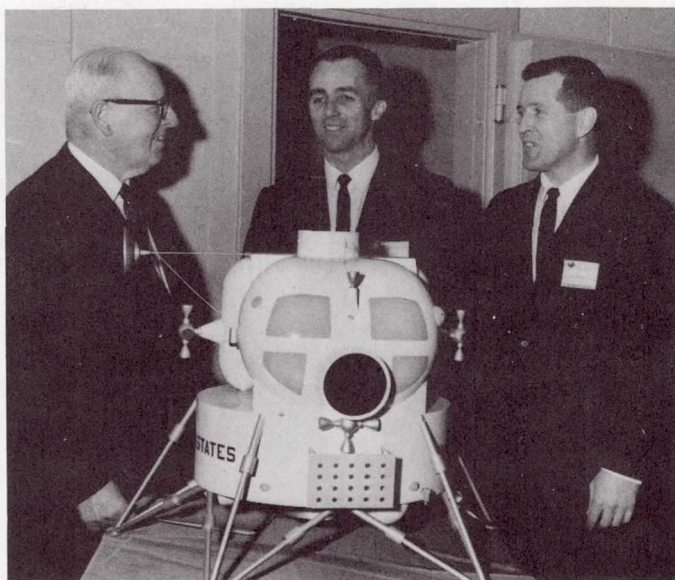
END OF A PHASE

Fitting Apollo's final two jigsaw pieces, the mode and the lunar landing vehicle, into the picture had closed a phase for NASA. For four years, the space agency had been planning, defining, or defending some facet of what led up to and became Apollo. NASA now faced a period of developing and testing hardware and then a time of attaining the operational experience needed to land men on the moon. The past year, 1962, had been the most strenuous, not only because of Apollo's crowded activities but because Mercury and Gemini had demanded so much attention.

Project Mercury enjoyed a banner year in 1962, with three manned earth-orbital flights: John Glenn in *Friendship 7* (Mercury-Atlas 6) on 20 February, Scott Carpenter in *Aurora 7* (MA-7) on 24 May, and Walter Schirra in the six-orbit flight of *Sigma 7* (MA-8) on 3 October. These, plus a good Saturn I flight on 16 November, gave the operations people experience in conducting actual missions.

It was becoming clear to Walter Williams and Christopher C. Kraft, Jr., Houston's mission and flight directors, that something larger and better equipped than the Mercury Control Center at Cape Canaveral would be needed for Projects Gemini and Apollo, with their longer and more complex missions. Flight controllers were spending a disproportionate amount of time traveling from Houston to the Cape—time that could more profitably be used for discussing ways of getting better performance from the spacecraft systems, training a larger cadre of flight controllers, and studying methods for handling Apollo missions.⁸⁰

Congressman George Miller (left) examines a one-eighth-scale lunar module shown by Grumman officials Joseph Gavin and Robert Mullaney.



The Houston group began pushing hard for an “Integrated Mission Control Center” at the new Clear Lake site southeast of the city. “Integrated” meant not only transferring flight control from the Cape but also moving computer programming and operations to the Texas center. Computer functions, including tracking and communications, had been Goddard’s responsibility during Mercury. Harry Goett’s team at the Maryland center had worked out plans for expanding the Manned Space Flight Network developed for Mercury to several times the size it was then. To this team, it seemed logical to keep this function in its own capable hands. Administrator Webb, however, agreed with Williams and Kraft, at least in part, and announced on 20 July 1962* that the main Apollo control center would be in Houston. But the location of the primary computer complex and the division of labor for the manned space flight tracking and communications network was still unsettled at the end of 1962.⁸¹

Project Gemini operations in 1962 essentially paralleled those of Phase A—earth-orbital—for the Apollo spacecraft. The Gemini team was busy with detailed systems and subsystems definition and subcontracting. McDonnell’s engineering mockup of the Gemini spacecraft was ready for review by Houston officials on 15 and 16 August. As the inspection began, Russian cosmonauts Andrian G. Nikoleyev in *Vostok III* and Pavel R. Popovich in *Vostok IV* landed safely after flights that, at first glance, seemed to have accomplished two Gemini objectives designed to gain experience for Apollo—long duration and rendezvous.

*At a celebration given on 4 July 1962 by the Houston Chamber of Commerce to welcome Manned Spacecraft Center employees and their families to Texas, Gilruth had intimated that the new control center would be built at the Clear Lake site.



Newly chosen astronauts (left to right) Neil Armstrong, Frank Borman, James Lovell, Thomas Stafford, Charles Conrad, John Young (kneeling), Edward White, and James McDivitt watch the launch of Walter Schirra aboard Mercury-Atlas 8, in the next-to-last mission of the Mercury program.

Although the cosmonauts did log a combined time of nearly 166 hours, contrasting with less than 20 hours total time for the three Mercury pilots during the year, it soon became obvious that the Soviets could not maneuver their craft to rendezvous in space. Because the two Russians came within five kilometers of each other, however, Gemini engineers wanted to see if the Mercury spacecraft could be modified to rendezvous with a passive target. After intensive study, Kenneth Kleinknecht, the Mercury project manager, reported that the modifications would add too much weight—the spacecraft might not even reach orbital altitude.⁸²

The Gemini announcement in late 1961 had declared that “NASA’s current seven astronauts will serve as pilots in this program. Additional crew members may be phased in during later stages.” In April 1962, the agency began selecting a new group of pilots. Six months later, eight of the nine “astronaut trainees”* watched from the Florida shoreline as Schirra began his six-orbit flight. Across the ocean, people in 17 countries viewed the first European television broadcast, via the communications satellite *Telstar*, of a space launch in “real time.”⁸³

Amid these and many other activities—such as building offices and training, checkout, and test facilities and erecting launch pads—the feasibility and definition phases of Apollo ended for NASA Headquarters and the three manned space flight field centers. The next step, design and development, promised to be equally strenuous and demanding.

* The nine new members of the astronaut corps were Neil A. Armstrong, Frank Borman, Charles Conrad, Jr., James A. Lovell, Jr., James A. McDivitt, Elliot M. See, Jr., Thomas P. Stafford, Edward H. White II, and John W. Young. All except Armstrong and See were members of one of the armed services. See did not attend the launch because he was clearing up some personal business before reporting to the Houston center. The designation “trainee” soon disappeared, except in some official documentation.

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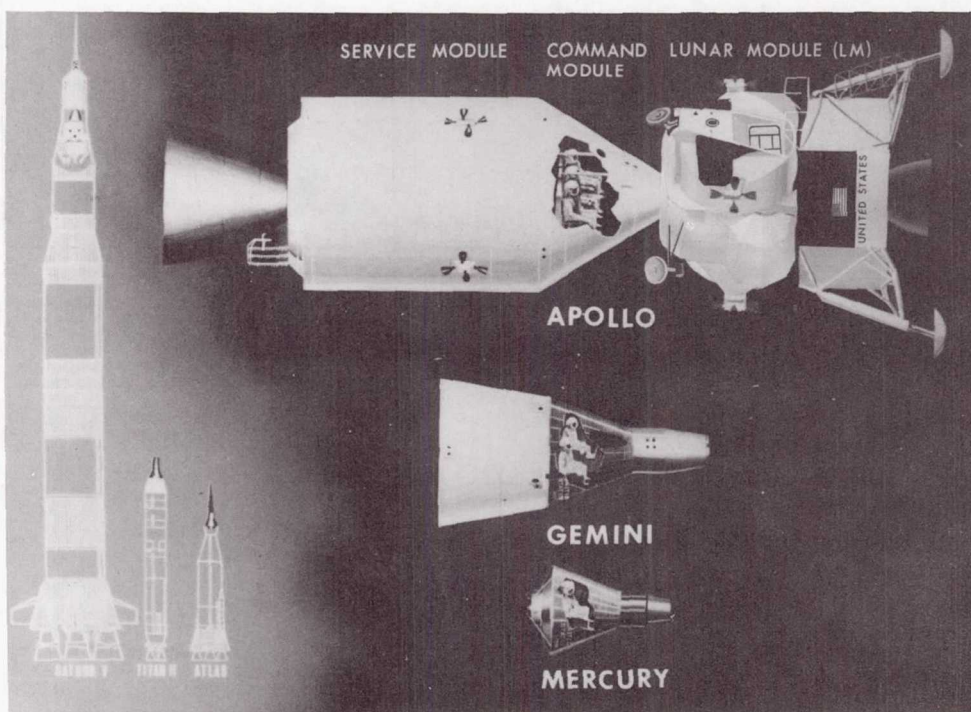
Command Module and Program Changes

1963–1964

Once all the vehicles in the Apollo stack had been decided on, those already being developed would have to be changed to fit the new concept of Apollo. Most immediately affected was North American's command module. The shape of this craft, a conical pyramid much like the bell-shaped Mercury, had been set very early. This blunt-body vehicle, however, had been designed only for earth-orbital and circumlunar flight, with some thought given to attaching propulsion stages to make a direct-flight, lunar-surface landing sometime in the future. Adoption of lunar-orbit rendezvous eliminated the need to land the command module on the moon but forced the inclusion of some means for docking that vehicle with the lunar module and transferring two astronauts into the lander for the trip down.

Command module development, then, took two routes. Configurations, systems, and subsystems had to be qualified and astronauts had to be trained in Apollo operations, which could be done in earth-orbital flight. It was therefore unnecessary to make any major changes on what came to be called the "Block I" spacecraft. But the time limitation set by the President did not permit waiting for the first version of the spacecraft to be completed and tested before starting on an advanced model, Block II, that could perform the new docking operation. The two spacecraft had many components in common, but development had become infinitely more complicated. Deputy Administrator Hugh Dryden termed the Apollo program "the largest, most complex research and development effort ever undertaken."¹

All three of NASA's manned space flight centers—at Huntsville,



Comparison of spacecraft and launch vehicle configurations.

Canaveral, and Houston—had their hands full during 1963 and 1964. Marshall was wrestling with the mammoth Saturn V development program; neither of the propulsion systems, the F-1 and the J-2 engines, could be simply picked off the shelves and fitted with appropriate oxidizer and fuel tanks. There were troublesome days ahead before the contractor, Rocketdyne, succeeded in developing and qualifying these engines so they could be trusted to boost astronauts toward the moon.² At the Cape, the Launch Operations Center was doing some educated guessing about the flight preparation facilities needed for the spacecraft and launch vehicles. And the Manned Spacecraft Center was working on three major programs: flying the last Project Mercury spacecraft (Mercury-Atlas 9) in May 1963 and getting spacecraft development under way in both Project Gemini and Project Apollo. Because of its modular configuration, Apollo had no immediate need for day-to-day coordination among the centers, which freed the program offices to work independently in solving their more pressing problems. But the program needed to be centrally managed—technically as well as administratively—far differently from Mercury, and it would have to be armed with a larger force to accomplish this. NASA Headquarters had, therefore,

COMMAND MODULE, PROGRAM CHANGES

to become more technically oriented and would have to participate more in the daily activities of the program.

THE HEADQUARTERS ROLE

Shortly after Brainerd Holmes joined NASA Headquarters as its first Director of Manned Space Flight, he and Administrator James Webb contracted with General Electric for studies on reliability and quality assurance, analysis and integration of the complete Apollo vehicle (spacecraft and booster), and procurement and operation of ground equipment to check out and certify the vehicles for flight. To fulfill this task, General Electric engineers would have to immerse themselves in the day-to-day activities of the space flight centers. No one in the field complained about General Electric's role in the reliability, quality assurance, and checkout functions, since the centers wanted all the help they could get in these areas. But the suggestion that a contractor should tell government employees how to put their vehicles together (the integration clause of the contract) to fly a mission was resisted. Edward S. Miller of General Electric said: "The contractor role in Houston was not very firm. Frankly, they didn't want us. There were two things against us down there. No. 1, it was a Headquarters contract, and it was decreed that the Centers shall use GE for certain things; and [No. 2] they considered us Headquarters spies." For some time after the contract award, just exactly what General Electric would do was not exactly clear.³

In February 1962, General Electric engineers began holding monthly review meetings, but they met with little success in selling their plans for spacecraft and launch vehicle integration. After several of these gatherings, contractor officials complained in August that there was "little understanding by NASA people as to the role of GE." That same month, General Electric nevertheless transferred 15 of its engineers to Houston. To get the contractor into Huntsville operations, the manager of the Headquarters office for integration and checkout accompanied several General Electric employees to Marshall to explain "GE roles in [the] Apollo program" to the center and Saturn contractor officials. Neither Boeing nor Chrysler wanted any "unannounced visits" by General Electric engineers, especially since the two principal Saturn contractors could not foresee any way in which General Electric could be of assistance to them. Marshall and the contractors were assured that all visits would be arranged in advance.⁴

General Electric's other major task, however—designing, setting up, and operating ground equipment to check out the flight vehicles—was accepted at the field centers. Manned Spacecraft and Launch Operations Center representatives said they were satisfied with the contractor's work in this area, and Marshall asked for more help. Even here, however, there were some reservations about turning General Electric loose. The Apollo manager in

CHARIOTS FOR APOLLO

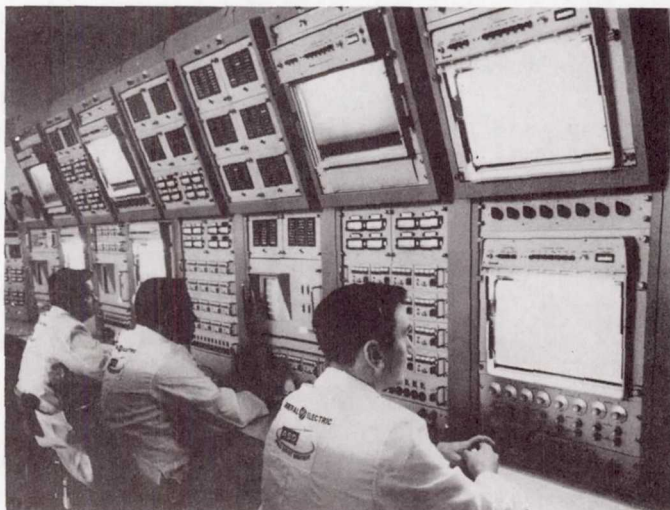
Houston, for example, warned the company, in capital letters, to do nothing unless it had "A WORK ORDER APPROVED BY THE APOLLO SPACECRAFT PROJECT OFFICE."⁵

Eventually, the General Electric contract called for almost a thousand persons, more than half of them stationed at Daytona Beach, near the Cape launch site, where they designed and assembled the ground checkout equipment needed to test the space vehicles for flight safety. The remainder went to the three NASA centers and to contractor plants, helping to ensure the receipt of good-quality hardware and performing specialized studies when they had a "work order."⁶

Webb had set up the General Electric contract to provide NASA Headquarters with the technical specialists to watch over and participate in Apollo's far-flung development activities in both government and contractor establishments. He also wanted a bevy of engineering system specialists near at hand to assist Holmes in making technical decisions. Webb asked Frederick R. Kappel, President of American Telephone & Telegraph Company, to form a group to provide this talent for Apollo. Bellcomm, Inc., the new AT&T division, began operating alongside Holmes' NASA Headquarters manned space flight engineers in March 1962. Holmes immediately directed the contractor engineers to work with Joseph Shea, his Office of Systems chief, first on the study of the mode issue and then on the defense of NASA's decision to land on the moon via the lunar-rendezvous method.

Once the route studies were completed, Shea decided that Bellcomm engineers should dip into mission planning and produce some "reference trajectories"—a careful analysis of everything involved in flying the space vehicles from the earth to the moon and back. But when he took his newly formed Apollo Trajectory Working Group to a meeting in Texas, Shea met with resistance. John P. Mayer, speaking for the mission planners in Houston, said that his group had been doing this kind of work for the past two

General Electric employees monitor activities of a spacecraft test in the automatic-checkout-equipment spacecraft control room in 1965.



COMMAND MODULE, PROGRAM CHANGES

years. He told Shea bluntly that interjecting Bellcomm into mission planning was just one more attempt on the part of Headquarters to move into operational areas that properly belonged to the centers. Shea explained that Bellcomm would be a supporting group and would not try to second-guess the centers.⁷

But many in Houston looked on Bellcomm representatives who attended many of the subsequent trajectory meetings as being, like General Electric, "Headquarters spies." What continued to rankle Mayer and his colleagues in trajectory analysis was that Bellcomm, not always on the scene, simply could not keep up with the latest operations data, mission rules, and guidelines. As a result, Bellcomm sometimes gave Headquarters out-of-date information, and the field centers had to spend much-needed time in correcting misconceptions. Nevertheless, Bellcomm, never numbering more than 200 persons, did produce some useful evaluations on almost every aspect of Apollo throughout the decade. These engineers were among the first to push for the pinpoint lunar landings that were so successfully carried out after the first landing mission.⁸

Along with the mounting strength in contractor personnel, the Manned Space Flight Office in Washington (only a handful of people in Mercury's early days) also increased in number. By February 1963, Holmes had a 400-man force, presided over by himself and his deputies, George Low and Joseph Shea. Low managed space medicine, launch vehicles, and office operations; Shea concentrated on engineering matters.⁹

Much of the energy of the Headquarters office and its contractors during 1963 was devoted to drafting an Apollo Systems Specification book. The aim of this document was to lay out the objectives, to define the technical approach for implementing these objectives, and to establish performance requirements. The task was difficult because many systems, especially those in the lunar module and the advanced command module, simply had not been studied in enough detail for anyone to state positively what was expected. Numerous pages were stamped "TBD"—to be determined. But there was some clarification of policy for Apollo. Up to this time, the main objective had been expressed only as landing a man on the moon and returning him safely before the end of the decade. The specification book intimated, for the first time, that exploration of the moon would not be limited to a single mission.¹⁰

A number of interesting specifications in the manual—intended for use as the Headquarters "bible" for all parties in the development of Apollo—remained valid throughout the program. For example, all parts of the spacecraft would be designed to minimize the fire hazards inherent in the use of pure oxygen atmosphere that North American had been directed to incorporate in the command module in August 1962. North American was instructed to design the command module so a single crew member could return the craft safely to earth from any point in the mission. And the

CHARIOTS FOR APOLLO

service module would provide all spacecraft propulsion and reaction control needs (spacecraft attitude changes in pitch, roll, and yaw) from lunar transfer until it was jettisoned just before the spacecraft reentered the earth's atmosphere.¹¹

Hand in hand with definition of the system specifications were the systems review meetings sponsored by the Office of Manned Space Flight. The meetings had a two-fold aim: to gather information for the specifications book and to make sure that the centers coordinated all activities in Apollo's complex development. At the first of these meetings, Shea found a gap in this coordination. Marshall was having trouble with F-1 engine combustion instability, yet an offer to help from Lewis Research Center—NASA's leading propulsion organization—had been ignored.¹²

Other instances of this lack of cooperation may have occurred, but the three manned space flight centers had moved closer together, partially to defend the mode choice and partially to stave off the intrusion of General Electric into vehicle integration. On top of that, each center had a great many questions that needed to be answered by the other field elements. And they were working together on policies and mission rules that became the foundation for the lunar landing program. At a mission planning panel meeting, some of these ground rules emerged: two crewmen would land on the moon and one man would remain with the command module in lunar orbit; the lunar lander could stay on the moon from 21 to 48 hours; launch from the earth would take place in daylight to simplify recovery operations in the event of an abort; launch to the moon from earth orbit would begin within 4½ hours because of the boil-off characteristics of liquid hydrogen in the S-IVB stage; and the first lunar mission would be only a loop around the moon and return, since too little was known about the start and restart capabilities of the service module engine.¹³

Most of these committees—and there were many, many of them—took turns meeting at Houston, Huntsville, and Canaveral. By May 1963, the panels were so numerous that Holmes realized that something had to be done to keep track of them. He told Shea to form a Panel Review Board*

* Board membership consisted of: from the Headquarters Office of Manned Space Flight (OMSF), Deputy Director, Systems, and Deputy Director, Programs; from Marshall (MSFC), Deputy Director, Research and Development, and two Associate Directors; from the Manned Spacecraft Center (MSC), Deputy Director, Development and Programs, and Deputy Director, Mission Requirements and Flight Operations; and from the Launch Operations Center (LOC), Assistant Director, Plans and Project Management. The authorized panels and their cochairmen were: Crew Safety, Joachim P. Kuettner (MSFC) and Alfred D. Mardel (MSC); Electrical Systems Integration, Hans J. Fichtner (MSFC) and Milton G. Kingsley (MSC); Flight Mechanics, Rudolf F. Hoelker (MSFC) and Calvin H. Perrine (MSC); Launch Operations, Rocco A. Petrone (LOC) and Walter C. Williams (MSC); Mechanical Design Integration, Hans R. Palaoro (MSFC) and Lyle M. Jenkins (MSC); Mission Control Operations, Fridtjof A. Speer (MSFC) and John D. Hodge (MSC); and Onboard Instrumentation, Otto A. Hoberg (MSFC) and Alfred B. Eickmeier (MSC).

COMMAND MODULE, PROGRAM CHANGES

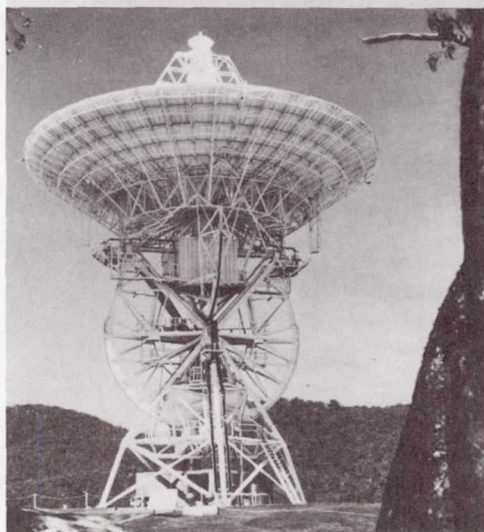
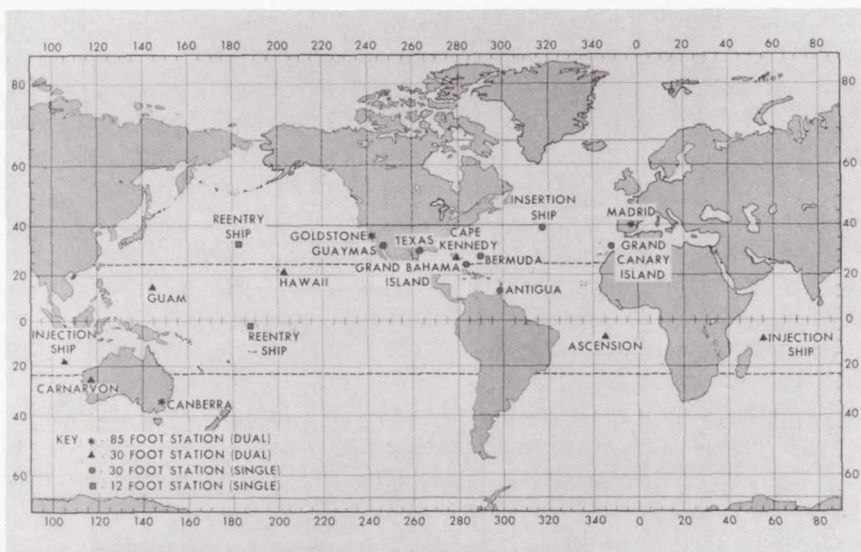
as one more Headquarters tool for managing Apollo.

Shea convened the first meeting of the board in August 1963 at the Cape, and representatives of each panel summarized their past activities. The next item on the agenda was a session on standardizing the Interface Control Documents (discussed in the previous chapter) and the selection of Marshall as the repository for this documentation, to make sure it would be available for reference by the participating organizations. These periodic board meetings, besides keeping the Office of Manned Space Flight closer to the mainstream of center activities, gave the specialists a chance to learn what their colleagues were doing and an opportunity to oversee progress, costs, and schedules. Areas that might delay Apollo were discovered more quickly and dealt with more rapidly.¹⁴

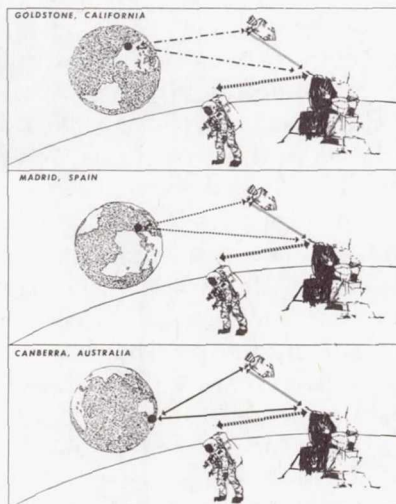
NASA Headquarters stepped in on occasion to arbitrate among the centers. At one time, telecommunications threatened to become a formidable issue in Apollo, with Houston, Goddard, and the Jet Propulsion Laboratory vying for control of the tracking network. The earth-circling band of stations—about a dozen and a half—used in Mercury were not equipped for the deep space communications of Apollo, but by 1963 a capability was developing in the unmanned spacecraft programs that promised to be suitable. Jet Propulsion Laboratory intended to build two sets of 26-meter dish antennas, with two antennas at each of three sites—Goldstone, California; near Canberra, Australia; and near Madrid, Spain—that would provide continuous communications coverage of the moon. One set would be equipped with the more advanced unified S-band system (a system that tied the signals for tracking, telemetry, voice, television, and command into a single radio carrier) for controlling, tracking, and acquiring data from unmanned spacecraft, like Mariner and Surveyor, in deep space. This system consolidated the functions of the many transmitters and receivers characteristic of Mercury into one.

The Mercury tracking stations, with 9-meter dishes and the new S-band radar, would communicate with the Apollo spacecraft in earth-orbital flight. Once the vehicle had traveled 16 000 kilometers into space, the 26-meter antennas—spaced equidistantly at 120 degrees longitude around the earth so one of the three always faced the moon—would take over. Later, the Jet Propulsion Laboratory was to build a 64-meter antenna at Goldstone (which then became the Goldstone Mars station) that gave Apollo clearer communications, especially in television reception. The laboratory wanted to construct two more of these stations, but the costs were too great. The British government, however, had a radar station with a 64-meter antenna at Sydney, Australia, that might be used.

Although some of the finer points on communications and control were haggled over for the next 15 months, in March 1963 NASA Associate Administrator Robert Seamans settled the basic issue of who was in charge and when. He assigned Goddard as the technical operator of the Manned



Apollo tracking network in 1966, above. Radar stations with large antennas for continuous tracking and communications were at Goldstone, California; Madrid, Spain; and Canberra, Australia. At left, the "big dish" at Canberra points toward space. Below, communications with the moon as the earth turned. Astronauts on the moon's surface also could talk to one another.



COMMAND MODULE, PROGRAM CHANGES

Space Flight Network; during Apollo missions, the Manned Spacecraft Center would assume operational control. The Jet Propulsion Laboratory would be in charge of all unmanned mission communications, turning its facilities over to the other centers during manned flights. By the end of 1964, Headquarters had the communications and tracking requirements and assignments for Apollo pretty well in hand.¹⁵

Other NASA Headquarters offices besides Manned Space Flight assumed lead roles for Apollo—especially in the area of scientific interest. Because of the complex engineering task, no one really expected that science would do more than ride piggyback. Almost the only concern the Houston center displayed was in the composition of the lunar surface soil, which would affect the design of the landing gear. Director Robert Gilruth sent a representative to a meeting of NASA's Space Science Steering Committee to ask for help on the soil question and to remind the members that whatever scientific equipment they might develop would have to be adaptable to the lunar spacecraft.¹⁶ But there was one area in which the scientists could be of more immediate assistance. How to land Apollo on the moon had been decided; how to get it there would be worked out by the guidance experts. Where to land it and what the astronauts could do after they got there was still unsettled.

Shortly after President Kennedy had issued the lunar landing challenge, Homer Newell of the Headquarters science office had asked Harold C. Urey of the University of California at San Diego to suggest the best scientific sites for lunar landings. Urey told Newell of five kinds of lunar terrain of particular scientific interest:

High latitudes—to check for possible temperature differences from equatorial areas. [Professor Harrison Brown had theorized, Urey added, that water might exist beneath the surface there.]

Maria—to try to determine the depth of holes where great collisions had taken place and, on a second landing, to discover the composition of the material in such places as the Sea of Tranquility.

Inside a large crater—to look at an area, probably Alphonsus, where observers had seen gases rising from the interior.

Near a great rille, or "wrinkle," in a maria—to attempt to find out what had caused it. [It had been suggested that water, rising from the interior, had cracked the surface as it dried.]

In a mountainous area—to observe crater walls.¹⁷

In 1962, a two-month summer study conference in Iowa was cosponsored by NASA and the National Academy of Sciences. The resulting de-

CHARIOTS FOR APOLLO

liberations, published as *A Review of Space Research*, outlined the broad objectives of a science program for Apollo. Conclusions were that the most important scientific tasks foreseeable for manned lunar explorations were educated observations of natural phenomena, the collection of representative samples of surface materials, and the installation on the moon of certain scientific monitoring instruments.

Late in 1963 and early in 1964, NASA Headquarters established science planning teams to recommend investigations of the lunar surface, designs for prototype long-life geophysical instruments, requirements for astronaut training, the building of a receiving laboratory for handling returned samples, and plans for the reduction and interpretation of geological, geophysical, solar, selenological, astrophysical, and other scientific data. Although the work of these teams was barely visible to outside scientists, NASA had some of the best specialists in the country helping to formulate its general objectives on the lunar science program.¹⁸

Five fundamental areas emerged as having the greatest potential:

Studies of the lunar lithosphere, the solid moon itself, its chemical and physical constitution, and the implications this should have for its origin in history.

Investigations of the gravitational and magnetic fields and forces around the moon, including experiments for the possible detection of gravitational waves.

Considerations of particles like solar protons and cosmic radiation, together with their effect on the lunar gravitational field and magnetosphere.

Establishment of astronomical observatories on the moon.

Studies of proto-organic matter, including the possibilities for exobiology.¹⁹

Realistically, everyone realized that the first manned visit to the lunar surface, limited to no more than 24 hours, would hardly satisfy the desires of most scientists. With proper planning, however, a bonanza of scientific results could be gleaned even from that first landing. In June 1964, the minerology and petrology planning team underscored these hopes by drawing an analogy between the lunar voyage and another historic event:

Some time before the year 1492, a group of workmen were standing in a shipyard looking at a half-constructed craft. One of them said "It won't float"; another said "If the sea monsters don't get it first, it will fall off the edge"; a third, more reflective than the others, said "What do they want to go for, anyway?"

COMMAND MODULE, PROGRAM CHANGES

The Apollo Project is primarily a glorious adventure, in which man will for the first time tread upon the surface of another celestial body. It will be a magnificent feat, and a milestone in the history of the human race. No other purpose or justification is necessary.

Important scientific knowledge will result from the landing. First among the scientific objectives of the Apollo mission will be the return of samples of the lunar surface materials. The study of such samples will tell us of the thermodynamic conditions under which they were formed; whether the moon is a differentiated body or not; and perhaps whether it was captured by the Earth or was formed from it in the distant past.²⁰

Most of the work of NASA Headquarters on behalf of the scientific aims of Apollo by the end of 1964 had little impact on the organizations and contractors developing the program. All that the builders needed to know was how much space to allow—and this would be minimal—and a general idea of the future plans. When the time came to fly the missions, however, the planners, astronauts, and flight preparations technicians would have to pay more attention. The outline of what Apollo could contribute to science had been sketched; the details would be filled in later.

Perhaps the Headquarters action that had the most significant effect on Apollo was a change of leadership in the Office of Manned Space Flight. When NASA had signed Grumman in 1962 to develop the lunar module, Holmes had wanted the agency to ask for a supplemental appropriation for Gemini and Apollo costs (see Chapter 4), but NASA's top administrators—Webb, Dryden, and Seamans—had refused. Webb also refused to transfer funds from other programs to manned space flight. Holmes and Webb had different views of management methods and of the priority of the manned program versus the rest of the space effort. The Administrator feared an all-out effort to land a man on the moon—one that subordinated all else—would endanger NASA's balanced program of seeking U.S. preeminence in space science and technology. The Manned Space Flight Director felt he had an overriding mandate from the President to win a race to the moon. The question of funds and priorities was taken to the White House. When President Kennedy cited the importance of the lunar landing, Webb agreed that it was important but said that he would not take responsibility for a program that was not properly balanced. Kennedy accepted his position.

Then in the first half of 1963 came the realization that Project Gemini was suffering from more technical troubles than had been anticipated, which would push the costs of that program past the billion mark, almost double the original estimates. Gemini schedule stretchouts followed. Holmes testified in March congressional authorization hearings that the administration refusal to ask for a supplemental appropriation had delayed the Gemini and Apollo programs four or five months. In the renewal of Holmes-Webb

CHARIOTS FOR APOLLO

differences over priorities, the President again backed his space program administrator. Shortly thereafter, NASA announced that Holmes was returning to industry.²¹

Moving to concentrate his resources on resolving Gemini and Apollo problems, Administrator Webb had decided to conclude the Mercury program after the ninth mission and to realign NASA organization throughout Headquarters and the responsive field center elements. One of the first requirements was to find a new leader for manned space flight. After considering several candidates, Webb asked Ruben F. Mettler, President of Space Technology Laboratories, Inc., to take the job. Mettler refused but recommended George E. Mueller (pronounced "Miller"), his Vice President for Research and Development. Webb accepted the recommendation, and Mueller became NASA's Associate Administrator for Manned Space Flight. With a doctorate in physics (Ohio State, 1951) and 23 years academic and industrial experience, Mueller had made many contributions to the country's missile and spacecraft programs.

Mueller had worked on Air Force manned space flight studies as early as 1958; later his laboratory had provided NASA with data that helped in making the Apollo mode decision. Furthermore, Mueller was familiar with NASA's relations with industry, both at Headquarters and the field centers, and had studied ground support equipment problems and tracking network issues as a system analysis contractor. But most useful to NASA was his recent work with the Air Force on performance, schedule, and budget constraints for the Minuteman missile. Derivatives of this background—program control offices, schedules and resources planning, and the subsystem manager technique—were to be incorporated into Apollo to strengthen Headquarters and field center control over cost, configuration, and schedules.²²

Soon after joining NASA, Mueller asked Air Force Brigadier General Samuel C. Phillips to help him apply to Apollo the kind of configuration and logistics management procedures established for Minuteman. Phillips brought with him about 20 officers to fill key positions. Mueller realized that this sudden infusion of Headquarters-level personnel might be detrimental to relations between his office and the field activities. To forestall any resentment, he invited center directors Gilruth, Wernher von Braun, and Kurt Debus to be his houseguests, to get to know them informally and to discuss with them his plans for Apollo. Mueller then visited Huntsville, Houston, and Canaveral. After completing the circuit, he began pressuring the field elements to conform to a long-range plan of program management.²³

In his attempts to inaugurate effective Headquarters control of Apollo, Mueller still faced vestiges of field center autonomy. The intercenter groups had gone far in working out system specifications and planning for vehicle integration; in Mueller's view, however, they had not gone far enough. To get to the moon by the set time, he told von Braun, Gilruth,

COMMAND MODULE, PROGRAM CHANGES

and Debus, Headquarters would have to be the final authority in administering a unified and coordinated plan of program control.²⁴

Mueller decided to make some changes in one management tool instituted by Holmes in late 1961. In a meeting of the Manned Space Flight Management Council* on 24 September 1963, Mueller said that too many persons were on the council and that it would henceforth be composed only of himself, von Braun, Gilruth, and Debus. This new, slimmed-down body would act as a board of directors in making decisions and managing Apollo and would expect to be frequently and thoroughly briefed on all Apollo matters, down to the nuts and bolts, by top technical managers. To make sure that the industrial leaders in the program were kept abreast of progress and problems, Mueller also intended to form an Apollo Executives Committee, of company presidents, which would tour the appropriate NASA facilities and then hold periodic reviews thereafter. These men, Mueller knew, could put pressure on their people to solve any development problems.²⁵

Webb, Dryden, and Seamans recognized in mid-1963 that NASA (and Apollo) had grown too large for Seamans to continue as "operating vice president," which he had been since 1961. They decided to give Seamans three "Associate Administrators" for specific activities: Mueller would manage the Office of Manned Space Flight and the three centers working on manned missions—Huntsville, Houston, and Canaveral. Homer Newell and Raymond L. Bisplinghoff would hold similar positions for the Office of Space Science and Applications and the Office of Advanced Research and Technology. Mueller revamped his own office, dividing it into five sub-offices (the five-box system)—(1) program control, (2) systems engineering, (3) test, (4) flight operations, and (5) reliability and quality—for each major program, Apollo and Gemini, reporting to a program director who would in turn answer to Mueller. Mueller kept the job of acting Apollo manager for himself and gave Gemini responsibility to Low. The manned spacecraft centers were directed to organize their program offices accordingly.²⁶

While the reorganization was going on, Mueller asked two veterans in

* The council, established on 21 December 1961, originally consisted of Holmes, his directors in OMSF (Charles H. Roadman, Aerospace Medicine; Milton W. Rosen, Launch Vehicles and Propulsion; and William E. Lilly, Program Review and Resources Management), and his deputies (Shea, Systems Engineering, and Low, Spacecraft and Flight Missions); Wernher von Braun, Director, and Eberhard F. M. Rees, Deputy Director (MSFC); and Gilruth, Director, and Walter C. Williams, Associate Director (MSC). By 27 February 1962, James E. Sloan, Holmes' Director of Integration and Checkout, and Kurt Debus, Director, LOC, had been added. On 26 and 27 February 1963, three new names appeared on the council rolls; James C. Elms, Deputy Director, Development and Programs (MSC); Albert F. Siepert, Deputy Director (LOC); and Robert F. Freitag, Director, Launch Vehicles and Propulsion (OMSF—replacing Rosen). During 1963, George M. Knauf took over from Roadman as Director of Aerospace Medicine.

CHARIOTS FOR APOLLO

his office, John Disher and Adelbert Tischler, for a study of Apollo's chances of landing on the moon by 1970. From the information they gathered on the existing technical problems, Disher and Tischler concluded that prospects were one in ten. After reading this pessimistic report, Mueller knew the adverse schedule trend would have to be reversed. When MSC Director Gilruth sent a representative to Headquarters in late September to find out if the four manned Saturn I flights Washington had planned could be reduced to three, Mueller saw an opportunity to begin tightening the schedules. He reviewed a Bellcomm study that recommended terminating the Saturn I launch vehicle program after the tenth flight, which Marshall estimated would save \$280 million, and concluded that there was no reason to fly any manned Saturn I vehicles. Ironically, NASA had just selected 14 new pilots, bringing corps strength to 30.* Administrator Webb worried briefly that the astronauts might not get enough space flight experience with the cutback, but Mueller reminded him that Gemini would fill that gap. Mueller added that there was a much better chance of beating the deadline if NASA had to man-rate only two boosters, the Saturn IB and V, instead of three.²⁷

Hard on the heels of the Saturn I decision came another pronouncement that was just as startling—if not more so—to the field centers. At a late October meeting of the Management Council, Mueller told Debus, von Braun, and Gilruth that “we can now drop this step-by-step procedure” of flight-testing. All parts of the spacecraft and launch vehicle would be developed and thoroughly tested at manufacturing plants and test sites before being delivered to the Cape as ready-to-fly hardware. There would no longer be any need for piece-by-piece, stage-by-stage qualification flights of the vehicles. Each launch was to be prepared as though it were the ultimate mission, to avoid dead-end testing, with its narrow objectives and hardware components not intended for the lunar missions.²⁸

Although the chances for getting to the moon within the allotted time may have improved, Apollo now had more launch vehicles and pads than were needed to do the job. When contracts were awarded, from late 1961 through 1962, step-by-step testing had been the norm. Hardware was purchased and facilities were built to carry out this time-tested practice. Mueller's all-up decision changed the rules, limited the number of Saturn I launches, and made it likely that not all of the Saturn IBs contracted for would be flown in mainline Apollo. These results raise an interesting, though moot, question. If this decision had been made before the contracts

* The astronauts in the third group (announced 18 October 1963) were Edwin E. Aldrin, Jr., William A. Anders, Charles A. Bassett II, Alan L. Bean, Eugene A. Cernan, Roger B. Chaffee, Michael Collins, R. Walter Cunningham, Donn F. Eisele, Theodore C. Freeman, Richard F. Gordon, Jr., Russell L. Schweickart, David R. Scott, and Clifton C. Williams, Jr. As in the second group, only two (Cunningham and Schweickart) were not members of the military services.

COMMAND MODULE, PROGRAM CHANGES

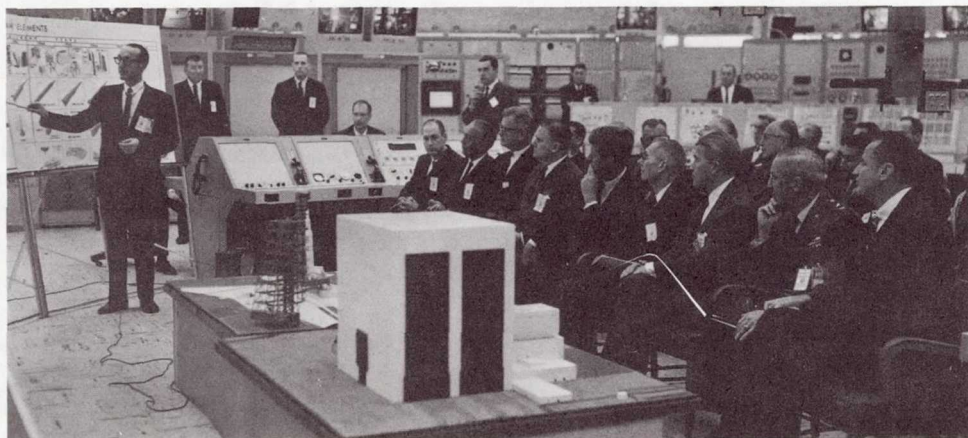
were awarded, would there have been both a Saturn I and a IB? An earth-orbital and lunar-orbital version of the command module? Later, NASA had to find some useful employment for the excess vehicles, eventually assigning them to the Skylab and Apollo-Soyuz programs. But this did not worry Mueller in late 1963. His job was to figure out how to get men on the moon within the time set by President Kennedy.

Shortly after Headquarters reorganized for improved management of Apollo and Mueller made his changes to enhance the chances for meeting schedules, the whole nation was wracked by a series of traumatic events. President Kennedy was assassinated, and his alleged killer was murdered while the country watched. No one who had access to a television set can ever forget those days. In the soul-searching that followed, national goals and social priorities were questioned. Periodicals such as *Science* were soon attacking what they called NASA's misplaced priorities, and books like *The Moon-Doggle* were expressing disillusionment with Apollo.²⁹

Although caught up in the grief of the times, the Apollo worker—manager, engineer, technician—had been and still was deluged by the complex tasks inherent in developing and qualifying the vehicles.

COMMAND MODULE: PROBLEMS AND PROGRESS

The lateness of the decision on how to fly to the moon had forced the Manned Spacecraft Center and the contractor, North American, to delay work on the command and service modules. Once the choice was made, they

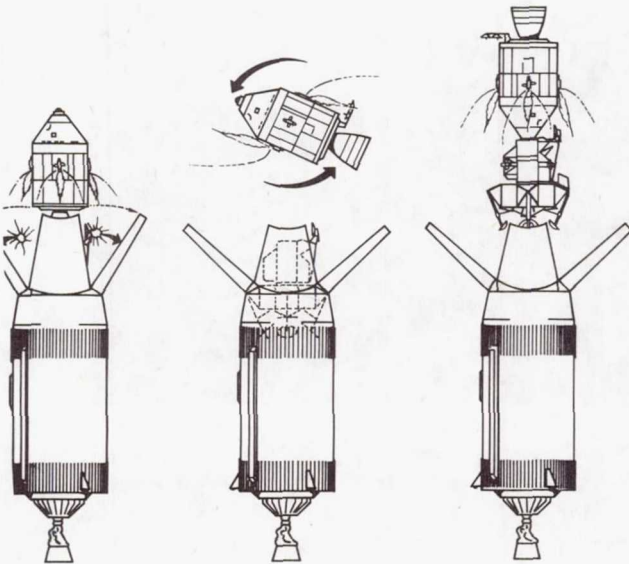


On 16 November 1963 in Cape Canaveral's Blockhouse 37, NASA's new manned space flight chief George Mueller briefed (left to right, front row seated) George Low, Kurt Debus, Robert Seamans, James Webb, President John Kennedy, Hugh Dryden, Wernher von Braun, Gen. Leighton I. Davis, and Senator George Smathers on Apollo program plans. The models on the table—Vehicle Assembly Building, Saturn V launch vehicle on crawler, and mobile service tower—represented key elements in the Apollo mission.

CHARIOTS FOR APOLLO

realized that much of what had been done had no place in the lunar-orbit rendezvous scheme. But that was not the only problem. NASA still insisted on having an earth-orbital command module, even though it could not dock with the lunar module, to train crews and flight controllers in the basic functions of the spacecraft. The definitive contract for that vehicle, however, had not been negotiated. In late 1961, NASA had issued a letter contract to North American, which would be extended as necessary, outlining in general terms what the spacecraft would be like. When all of Apollo's pieces were finally picked, it was time to reach an agreement with North American on the precise details of the spacecraft.

Charles Frick, the Apollo manager in Houston, assigned his special assistant, Thomas Markley, to negotiate the definitive contract with North American and its principal contractors. When deliberations started, on 7 January 1963, the Manned Spacecraft Center was facing crowded conditions in its temporary locations along the Gulf Freeway. Markley and his government team therefore met the contractor representatives in 16 rooms on the 13th floor of the Rice Hotel in downtown Houston. Signaling the start and finish of 15-hour work days, Monday through Saturday, with a cow bell, Markley and the groups completed the "basic contract package" on 26 January. The proposed contract then had to travel through administrative levels until it reached Webb for final approval or refusal. As the document journeyed through channels, the cost figures on the subsystems were revised. On 24 June, the estimated value was \$889.3 million (without fee). When it was finally approved in August, the price, with \$50-million fixed fee, was \$934.4 million. For this sum, NASA was to receive 11 mockups (fac-



Once the S-IVB stage placed the spacecraft on a trajectory to the moon, the spacecraft-lunar module adapter panels would blossom outward 45 degrees (later they were discarded by explosion). The Apollo command and service modules would separate from the stage, pull away, turn around, dock with the lunar module, and then pull the LM away from the stage.

COMMAND MODULE, PROGRAM CHANGES

simile models), 15 boilerplate capsules (test vehicles), and 11 flight-ready spacecraft.³⁰

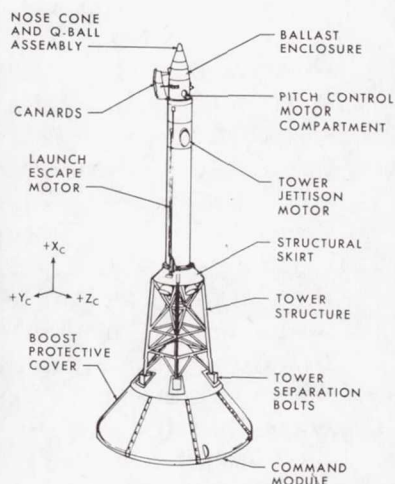
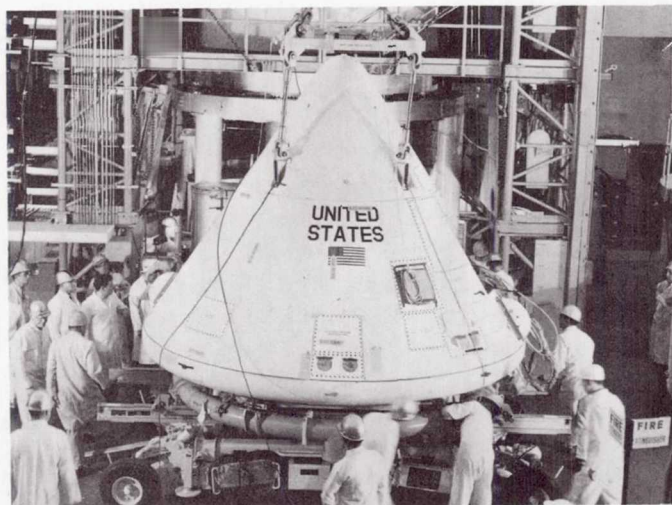
Under the letter contract, many of these items had gone into the manufacturing cycle, with scheduled delivery dates. Immediately after contract approval, Mueller sent his two deputies, Low and Shea, to Downey, California, to find out why North American was late on those deliveries. Harrison Storms, president of the division building the command module, briefed the visitors on the problems and admitted to a 10-month slip in schedule for the first command module earmarked for orbital flight. Storms counter-attacked, however, reminding the NASA customers that some of their decisions had been late in coming and that orders to change some of the subsystems had slowed factory schedules—and were still doing so.³¹

Another item changed Apollo manufacturing plans in Downey. NASA officials learned that North American intended to build the spacecraft–lunar module adapter* in Tulsa, Oklahoma. The Air Force had decided to cancel the Skybolt missile development program and to keep using Hound Dog missiles, which were manufactured in Downey. When the Air Force ordered more Hound Dog vehicles and demanded that production in Downey continue, some Apollo work had to be done elsewhere.³²

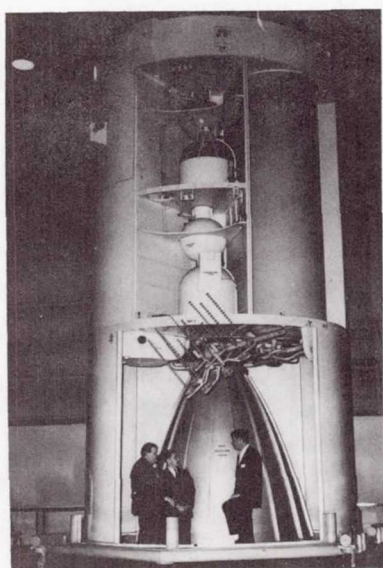
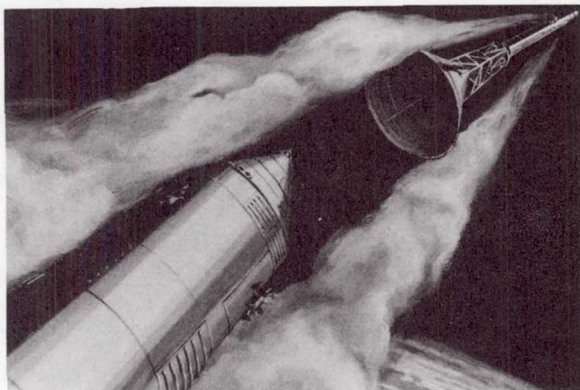
One chief aim of the 1963–1964 period was to get both versions of the command module far enough along for a formal mockup review board to accept them as the final configuration. With a great deal of this work being done simultaneously, the task was extremely onerous. John Paup, command module manager at North American who had fretted over the slowness of the mode decision, wanted to get the systems of the earth-orbital Block I spacecraft set so he could begin production on that vehicle. At the same time, he was anxious to get the exact differences between the two vehicles delineated. Joseph Shea, who had by now replaced Frick as Apollo manager in Houston, told Paup that Block II definition was not going to be easy to arrive at, with the Block I configuration still not settled.

Paup contended that several areas of common interest between the two vehicles had to be resolved immediately. One of the debates was whether to use strakes, tower flaps, or canards to stabilize the command module in the event of a launch abort. Whichever was used, the object was to get the spacecraft down in what was called the “BEF” (blunt end forward) position. Strakes were semicircular devices near the top of the heatshield that would keep the vehicle from landing on its nose. Recent changes in the subsystems had shifted the vehicle’s center of gravity, which forced a lengthening of the strakes to handle the aerodynamic change. After

* The lunar module nestled inside the adapter (SLA) from launch through separation of the service module from the S-IVB. The honeycomb panels of the adapter were then explosively fired to allow the command and service modules, after turning around and docking with the lunar module, to pull the lander from the booster’s third stage.



Full-scale model of the command module, above: the strake aerodynamic devices may be seen at either side of the spacecraft just above the aft heatshield. On the drawing of the launch escape system at upper right, the canard aerodynamic devices are near the top of the escape tower. Jettison of the launch escape system (right), after successful launch, also pulls away the boost protective cover that protects the windows from flame and soot.



Full-scale model of the service module, resting on a mockup of a spacecraft-lunar module adapter, with panels off to reveal part of the internal arrangement.

COMMAND MODULE, PROGRAM CHANGES

heat-resisting ablative material was added to the longer strakes, however, they weighed too much. North American suggested using either tower flaps (fixed surfaces near the top of the launch escape tower) or canards (deployable surfaces on the forward end of the escape-rocket motor). Paup wanted to know which to install, and Shea told him to put canards on Block I and then look for some way to eliminate all these devices on Block II.³³

Another decision that would influence both spacecraft was on whether to set the vehicle down on land or water, a question that had been under discussion since mid-1962. During a meeting in early 1964, a North American engineer reported that "land impact problems are so severe that they require abandoning this mode as a primary landing mode." That was all Shea needed to settle that debate. Apollo spacecraft would land in the ocean and be recovered by naval ships as Mercury had been.³⁴

Throughout 1963 and 1964, there were frequent meetings on command module subsystems that were common to both versions of the craft. Because space missions would be of longer duration, a concept had developed very early that the astronauts would repair or replace a malfunctioning part in the spacecraft during flight. This plan would require tools and spare parts to be carried on the missions and created another weight problem. At a subsystems discussion in April 1964, Shea told the North American engineers that NASA no longer favored this method of ensuring good working components in space. Instead, the contractor was to work toward reliability through manufacturing and test processes and by installing redundant systems. If something did go wrong, the crew should be able to shift to another system that could perform the same function as the malfunctioning one. Houston also wanted the contractor to upgrade its reliability program by improving its failure reporting practices, manufacturing schedules, engineering change controls, test plans, traceability methods, means of standardizing interface control documents, and ground support equipment provisioning.³⁵

Houston had already taken measures in late 1963 to increase its control over and improve on subsystem development, chiefly to get the more advanced Block II command module under way. Shea asked Max Faget, chief of the Engineering and Development Directorate at the Manned Spacecraft Center, to pick experts in the engineering shops to act as subsystem managers. The managers were directed to oversee their components from design through manufacture and test. They were responsible for cost, schedules, and reliability. When changes in one unit became necessary, other systems had to be considered, and any conflicts resolved, before alterations could be made. The subsystem manager concept was therefore an excellent device for restraining engineers eternally eyeing good hardware for chances to make it better.³⁶

North American and Grumman also made significant contributions to-

CHARIOTS FOR APOLLO

ward controlling hardware development. As far back as mid-1962, John Disher had urged Houston to draft hardware development and flight test schedules through the first manned lunar landing. Houston submitted these schedules in October 1962. When 1963 rolled around, delays of one kind or another had made this paper nearly meaningless. Near the end of the year, North American invited the other two major contractors, Grumman and MIT, to help settle this issue. The contractors drew up charts on all three modules—command, service, and lunar—looking at development tests of subsystems, ground tests of partial and fully assembled modules, and Saturn-boosted flight tests of completed modules. Formally known as the “Apollo Spacecraft Development Test Plan,” their report to NASA, outlining the tests and exact uses of every piece of hardware for the years 1964 through 1968, was called “Project Christmas Present” by the contractors.³⁷

A second move, led by Grumman, was made in the early months of 1964. Grumman officials had complained to Shea that the frequent changes in the lunar mission concept made it impossible for the design and development engineers to decide what components they needed. The general outline of the mission was pretty well set, but the haziness about specific refinements was playing havoc with attempts to design hardware to cover all normal and contingency operations. Shea told Grumman to see if it could get the requirements pinned down. North American and MIT crews soon joined the lunar module contractor team to come up with a “Design Reference Mission.”

First the group looked at what Apollo was supposed to accomplish: “Land two astronauts and scientific equipment on the near-earth-side surface of the moon and return them safely to earth.” A second major objective was to carry more than 100 kilograms of scientific equipment to be set up on the moon and to bring back more than 30 kilograms of lunar soil and rocks. To make sure this was understood, the study group would have to analyze every moment of a hypothetical mission—on the ground, in space, on the moon, and during the return to the earth—from the time the stacked vehicles were rolled toward the launch pad until the command module was recovered in the Pacific Ocean. In other words, the North American-led study concentrated on getting reliable hardware to the launch pad; the Grumman-sponsored task aimed at making sure that the equipment would be able to handle the job of getting to the moon and back.

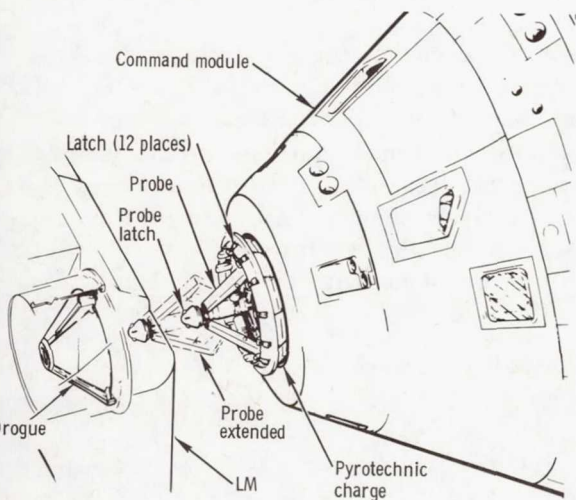
The group soon realized it had to pick out an arbitrary mission launch date—it chose 6 May 1968—to give realism to the plan and to focus attention on every move, every procedure, in the minutest detail. Working out the specific position of the moon on that date in relation to the earth, members drew up a precise launch trajectory. Then, assuming a given number of hours spent in flight and on the moon, they calculated the corrections in the return trajectory that would have to be made to accommodate changes in the moon-earth position. The task was not an easy one. It took four months

COMMAND MODULE, PROGRAM CHANGES

of "working like hell" to produce three thick volumes describing the sequence of events and related actions. The work would have to be updated later, of course, but the contractors had a better understanding after the exercise of what their subsystems should be and what they should do. Thus, long before the astronauts embarked on an actual lunar landing mission, the mission planners, government and contractor, had spent untold hours agonizing over every minute of that trip.³⁸

The design reference mission study led neatly into the requirement for North American to accelerate Block II command module work. That vehicle had moved slowly following the lunar-orbit mode decision, but it would have been almost impossible to increase the speed. Until Grumman got the lunar module design relatively well set, North American engineers would have only the most general ideas of how the two vehicles would rendezvous and dock, which limited them to guesses about the influence of the docking equipment on the command module weight. The following spring, however, new mission rules gave them a clearer picture of what they were designing toward: the crew members would be able to stay in their couches during docking and the connection between the command and lunar modules would be rigid enough to maintain a pressurized pathway through which the astronauts could travel between the craft.³⁹

By mid-1963, North American engineers had begun work on an extendable probe on top of the command module that would fit into a dish-shaped drogue on the lunar module. They considered three possible ways of docking: (1) soft docking (latching with enough separation between the craft to make sure that pilot errors could not impair flight safety and then reeling the vehicles together), (2) hard docking (going straight in and latching without preliminaries) as a backup mode; and (3) transferring the crew by extravehicular means (getting out of one spacecraft in free space and climbing into the other vehicle) in an emergency situation. It was now apparent that the main difference between the Block I and Block II space-



North American engineers favored probe and drogue devices to dock the command module with the lunar module. The CM probe would slip into the LM's dish-shaped drogue, and 12 latches on the docking ring would engage, to lock the spacecraft together, airtight. The astronauts could now remove a hatch, take out the docking devices, and travel between the two spacecraft. When operations were finished, they would return to the CM, reinsert the devices, install the hatch, and release the latches to disengage from the LM.

CHARIOTS FOR APOLLO

craft was that Block II would be equipped with the means for docking and the pressurized crew transfer tunnel, but Block I would not.⁴⁰

By March 1964, Manned Spacecraft Center and North American were close to agreement on the design of the Block I command and service modules. A Mockup Review Board* was getting ready to go to Downey, with a team of systems and structural specialists, to examine every part of the proposed model and decide what items to accept. Following NASA tradition in engineering inspections, the board would consider four categories of changes: items (1) approved for change, (2) accepted for study, (3) rejected outright, and (4) found not applicable. The review board would rule on the suggested changes on the basis of technical accuracy, desirability and feasibility, and the impact on cost and schedules.

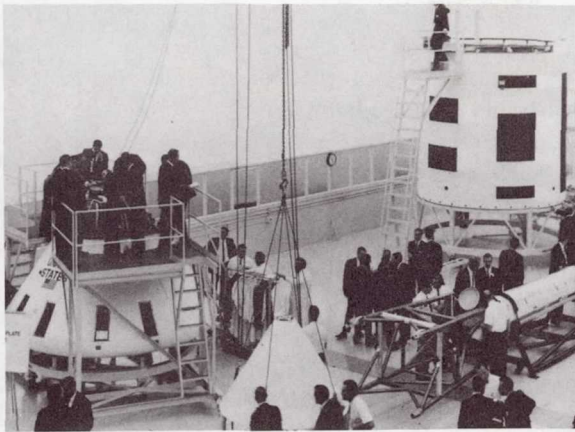
At the end of April 1964, a hundred persons gathered at North American's Downey plant. After being welcomed by contractor officials, members of the board and their specialists watched as several astronauts simulated operating the vehicle. Next came a walk-around for a general examination of the spacecraft mockup and such special displays as wiring, cutaway models of subsystems, parachute packing, and electrical connectors. Managers and counterpart engineers from NASA and the manufacturer then split up into small groups to examine minutely and evaluate each piece. More than a hundred requests for changes (RFCs) were written on the spot for consideration by the board; 70 were approved, 14 were designated for further study, and 26 were rejected.

The spacecraft couches worried the board members a great deal, since the crewmen, wearing pressurized suits, fitted too snugly into their seats. As a matter of fact, an astronaut lying in a couch could not move easily, even in an unpressurized suit. Three pilots lying side by side in the couch area would be virtually immobilized. By July, adjustments had been made to alleviate this situation and to cover other suggestions by the board and its assistants. After a second mockup review, in September, NASA told North American to begin production of the Block I, earth-orbital command and service modules.⁴¹

After Project Christmas Present and the decision to use redundant systems rather than making repairs en route to the moon, work on the Block II spacecraft began to move a little faster. Since two large vehicles, the command-and-service-module combination and the lunar module, would be boosted into space, a weight-reduction program became of major importance. North American met this challenge principally by shaving kilograms off the command module heatshield and the service module structure.⁴²

During the spring of 1964, continuing problems with the Block I and

* Christopher C. Kraft, Donald K. Slayton, Caldwell C. Johnson, Owen E. Maynard, and Clinton L. Taylor would act for NASA, and H. Gary Osbon and Charles H. Feltz for the contractor.



NASA and North American engineers at the April 1964 command module mockup review (above) closely examine all pieces of the Apollo command and service modules. While several engineers on the platform inspect the CM recovery system, the forward heatshield waits to be lifted into position. Groups of engineers of the various specialties (right) meet to discuss and list requests for changes for consideration by the NASA Review Board.



Astronaut James McDivitt (left) receives assistance with a shoe cover before entering the command module to check out the cabin from a pilot's viewpoint. One of the most worrisome items astronauts found in the CM arrangement was an "elbow-shoulder clearance problem." Four years later, in 1968, this problem still vexed astronauts Walter Schirra, Donn Eisele, and Walter Cunningham, the first crew to fly an Apollo spacecraft.



CHARIOTS FOR APOLLO

Block II vehicles triggered a change in management at North American. Dale D. Myers, program manager of the Hound Dog missile, took over as Apollo manager, replacing John Paup. Myers, a company employee since 1943, later remarked: "The first thing I did when I got on the program was to work out with Joe Shea . . . a program definition phase for Block II that [lasted from April] till October. We set up all the milestones we had to go through . . . in getting to the definition of the Block II vehicle."⁴³

Shea and Myers assigned teams at Houston and Downey to guide the definition phase of Block II. Alan Kehlet led the contractor team, and Owen Maynard headed the NASA group. Both men had worked on Apollo spacecraft design as far back as the feasibility studies of 1960. Under their leadership, teams concentrated on such activities as charting and evaluating changes caused by abandoning the inflight repair concept, finding places in the cabin for the lunar sample boxes, studying the design of the pressurized tunnel that permitted the astronauts to move from one vehicle to the other, eyeing the probe and drogue docking mechanism, reviewing the heatshield and service module weight-reduction programs, and modifying the service module design to provide an empty bay to hold the scientific experiment equipment.⁴⁴

Maynard and Kehlet planned to hold their Block II design review meeting in August, but it was 29 September before 130 board members* and specialists had something at Downey to examine. But even this was not a complete mockup of the advanced command module, as some NASA officials had expected. The contractor presented mockups of the command module interior, including the arrangement of the upper deck and lower equipment bay, and the service module with two of its four bays exposed. Although the couches from the April Block I review were still featured, the harnesses had been modified to afford roomier seating. The hatches—inner and outer—were the same as for Block I, and the spacecraft exterior reflected only the changes from Block I. New systems, such as docking and crew transfer, were sketched out in little detail.

After the specialists had examined the mockup, they submitted 106 requests for changes. The board accepted 67, recommended 23 for further study, rejected 12, and returned 4 as not applicable. What worried everyone, government and contractor employees alike, was the lack of good, solid information on how this vehicle and the lunar module would work together on rendezvous and docking. Across the continent at Grumman's New York plant, however, the lunar module contractor had a mockup that would be ready for formal review in October. That would give North American a clearer picture of the exact changes necessary in its spacecraft. In five

* Board membership had changed considerably. Maynard (Chairman), Faget, Slayton, Owen G. Morris, Taylor, and Sigurd A. Sjoberg represented NASA, and Norman J. Ryker, Jr., and Kehlet acted for North American.

COMMAND MODULE, PROGRAM CHANGES

months, after these changes had been studied and incorporated, a formal Block II command and service module review would be held. Meanwhile, one engineer from Houston and one from Downey would be assigned to each of the 67 requests for changes that the board considered critical.⁴⁵ Essentially, then, waiting for the lunar module to settle into its final form became a way of life for North American engineers.

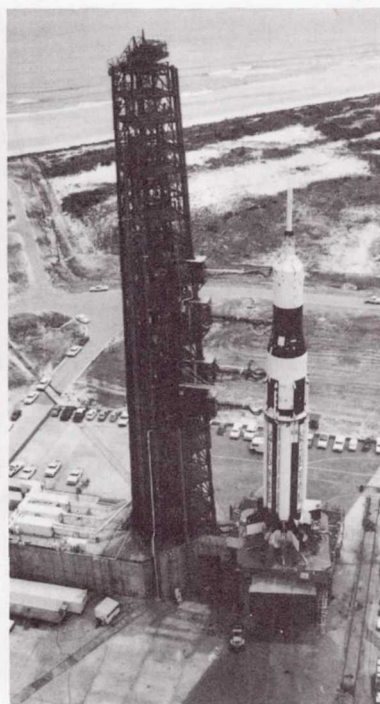
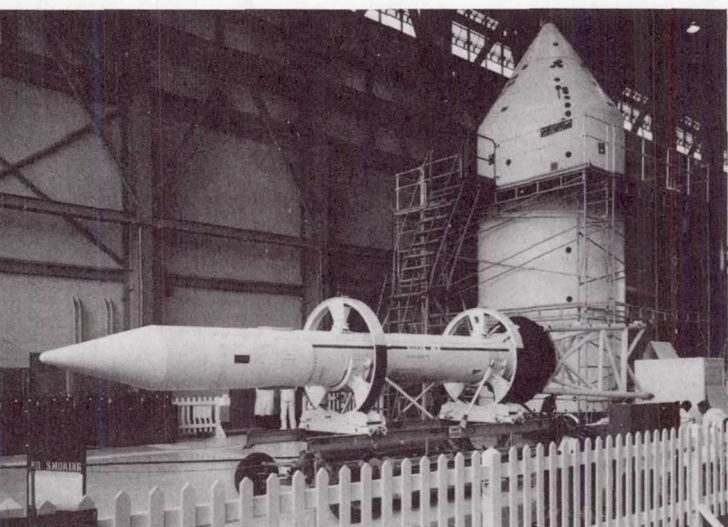
But some of the decisions on what would constitute the North American spacecraft were not influenced by the lunar module, nor were they based on theoretical studies and ground tests. Some came from actual missions.

At White Sands, New Mexico, on the morning of 13 May 1964, a Little Joe II launch vehicle rammed Boilerplate (BP) 12 to an altitude of 4700 meters, to see if the launch escape system could propel the spacecraft away from the booster after it had reached transonic speed. Only one incident marred an otherwise successful flight. A parachute riser broke during descent, collapsing one of the three main parachutes. The boilerplate landed safely on the two remaining parachutes, in what one engineer later called "a welcome unplanned result of the test."⁴⁶

As 1964 drew to a close, the Little Joe II abort test program at White Sands was nearing its third* and, in many ways, most crucial launch. Because of their fixed fins, the first two solid-fueled rockets had been somewhat erratic in flight. Jack B. Hurt's people at the Convair plant of General Dynamics in San Diego then built a relatively simple attitude control and autopilot system for the rest of their vehicles to allow hydropneumatic operation of "elevons," like ailerons, in each of the four fins while in flight. In addition, for the "max q" (maximum dynamic pressure) and high-altitude abort tests coming up, small reaction control motors were installed in the fin fairings to increase the precision of aiming control to the test points desired. Vehicle No. 12-51-1, as it was called, with four Recruit and two Algol motors, was the most powerful Little Joe II yet flown, intended to develop 1500 kilonewtons (340 000 pounds of thrust) to lift itself and its cargo—BP-23 and the launch escape tower—more than 9 kilometers high. The whole assemblage, weighing 41 500 kilograms, was pointed toward the north at a point in space where the launch escape system, fitted with canards, would pull the capsule and boost protective cover away from the Little Joe II while traveling at a speed of mach 1.5. This area was in the middle of the region where a Saturn V ought to experience max q.

At precisely 8:00 on the morning of 8 December, Little Joe II roared upward, straight and true. Thirty-six seconds later—almost out of sight and two seconds, or 900 meters, early—the planned abort took place. After an 11-second coast period, the canards deployed, and the capsule tumbled four

* The first Little Joe II, a qualification test vehicle without a payload, was launched successfully on 28 August 1963.



Full-scale models of the Apollo command and service modules and launch escape tower (foreground) are received in a hangar at the Kennedy Space Center for the first launch of an Apollo spacecraft by a Saturn vehicle—mission SA-6, 28 May 1964. At right, SA-6 spacecraft and launch vehicle ready to go.

times in its turnaround before stabilizing blunt-end forward and jettisoning the escape system. The boost protective cover shattered slightly more than expected, but the two drogue parachutes deployed. Its three main parachutes opened, and BP-23 drifted gently to rest, 11 000 meters uprange from the launch site, after 7.5 minutes of flight. Max q had been higher than predicted, but all else had worked well; at the end of 1964, Little Joe II, with its payload, was ready for more stringent flight tests.⁴⁷

Across the country, in Florida, engineers and technicians from California, Texas, Alabama, and elsewhere were grooming the first Apollo-configured spacecraft model to ride aboard a Saturn I booster. Although Saturn I was no longer part of the manned Apollo program, the SA-6 launch on 28 May did prove that Marshall could build a booster to fit the command module. In the jargon of the trade, “The mission was nominal.” After 54 earth circuits, BP-13 reentered the atmosphere east of Canton Island in the Pacific Ocean on 1 June. No spacecraft recovery was planned. Just three and a half months later, on 17 September, a nearly identical test of the seventh Saturn I and BP-15 had equally satisfactory results.⁴⁸

Thus, in the closing months of 1964, the final form of the command ship was emerging, the management team was in better shape to handle the program, and the mission planners had a clearer picture of the multitude of steps necessary in the performance of a lunar mission. During this two-year period, the lunar module also assumed definite shape.

6

Lunar Module

1963-1964

With the signing of the lunar module contract, the Manned Spacecraft Center and Grumman began the design and development of a vehicle that would land two men on the moon and, subsequently, take them off. When NASA selected Grumman in late 1962 to build this final piece in Apollo's stack, the landing craft was still a long way from a "frozen" hardware design. While the command and service modules were evolving from Block I to a more advanced Block II version during 1963 and 1964, the lunar module was also changing, moving toward the huge, spidery-legged bug that later landed on the moon.

EXTERNAL DESIGN

Houston and Grumman engineers had spent a month in negotiations and technical groundwork before signing the contract on 14 January 1963. Although ratification by NASA Headquarters was not forthcoming until March, Grumman forged ahead, devoting most of the first three months to establishing a practical external shape for the vehicle.¹

Cooperation between customer and contractor got off to a fast start. In late January, officials from the Houston Apollo office visited Grumman to review early progress, to schedule periodic review meetings, and to establish a resident office at Bethpage similar to the one already operating in Downey. Then, following a tradition that had proved effective in other programs,

CHARIOTS FOR APOLLO

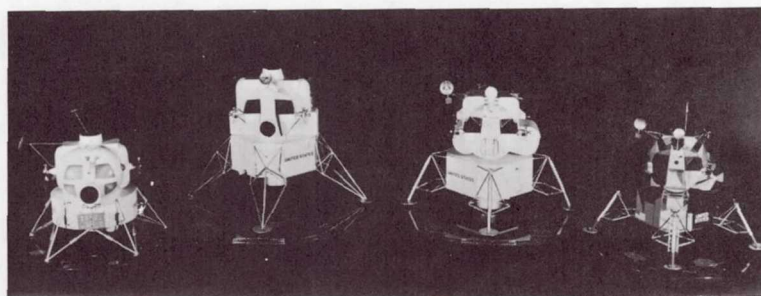
the Houston office set up spacecraft and subsystem panels to carry out technical coordination. Thomas J. Kelly had directed Grumman's Apollo-related studies since 1960, earning for himself the title "father of the LEM," but the vehicle that finally emerged was a "design by committee" that included significant suggestions from the Houston panels, notably Owen E. Maynard's group.²

Using Grumman's initial proposal for the lunar module as the departure point for continuing configuration studies and refining subsystem requirements, the team that had guided the company through its proposal spearheaded the design phase. When the contractor assigned 400 engineers to this task, an optimistic air about how long it would take pervaded both Bethpage and Houston. The job took longer than the six to nine months originally anticipated, however, because of special efforts to guard against meteoroids and radiation and to incorporate criteria imposed by the unique lunar environment.

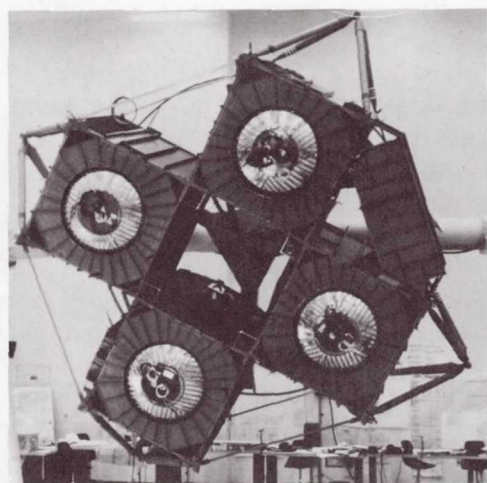
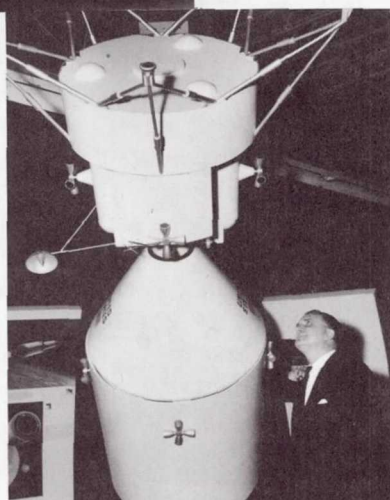
Basic elements in Grumman's proposal remained the same: the lunar module would be a two-stage vehicle with a variable-thrust descent engine and a fixed-thrust ascent engine; and the descent stage, with its landing gear, would still serve as a launch pad for the second, or ascent, stage.* But almost everything else changed. As a first step in defining the configuration, Grumman formed two teams to study the ascent stage. One group examined a small cabin with all equipment mounted externally, and the other studied a larger cabin with most equipment internal. The findings of the two teams pointed to something in between. The spacecraft that ensued was ideally suited to its particular mission. Embodying no concessions to aesthetic appeal, the result was ungainly looking, if not downright ugly. Because the lunar module would fly only in space (earth orbit and lunar vicinity), the designers could ignore the aerodynamic streamlining demanded by earth's atmosphere and build the first true manned spacecraft, designed solely for operating in the spatial vacuum.³

At a mid-April 1963 meeting in Houston, Grumman engineers presented drawings of competing configurations, showing structural shapes, tankage arrangements, and hatch locations. Grumman and Houston officials then worked out the size and shape of the cabin, the docking points, and the location of propellant tanks and equipment. The basic structure and tankage arrangement was cruciform, with four propellant tanks in the descent stage and a cylindrical cabin as the heart of the ascent stage, which also had four propellant tanks. Still to be resolved were questions of visibility, entrance and exit, design of the descent engine skirt (which must not impact

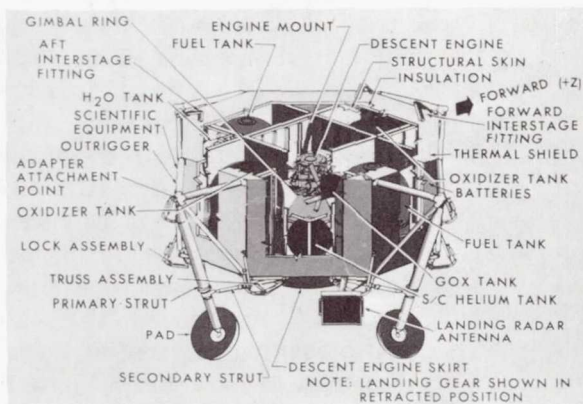
* The descent engine had another possible chore: to act as a backup propulsion system if the service module engine failed to fire on its way to the moon. No special modification to the descent engine was required, but the docking structure on the spacecraft had to be strengthened to withstand the shock of the firing.



Lunar module generations from 1962 (above left; the vehicle originally proposed by Gruman) to 1969 (a model of the version that landed on the moon). The second and third from the left are renderings for 1963 and 1965. NASA Administrator James Webb examines models of the lunar and command modules in docked position.



The underside of the lunar module descent stage shows fuel tank installation. The drawing of the stage indicates positions of components.



the surface on landing), and docking and hatch structures.⁴

In late April and early May, Maynard (chief of spacecraft integration in MSC's Spacecraft Technology Division) summarized for Director Robert Gilruth the areas still open for debate, especially the landing gear and the position of the landing craft inside the launch vehicle adapter. Another sticky question, he said, was the overall size of the vehicle, which dictated

CHARIOTS FOR APOLLO

the amount of propellants needed to get down to the moon and back into orbit. The lunar module structure, especially the descent stage, would be wrapped around the tanks; as the tanks were enlarged, the vehicle design would have to grow to accommodate them. There was one ray of light, however; Marshall was talking about increasing the lifting capability of the Saturn V launch vehicle from 40 800 kilograms to 44 200. With that capability, the target weight for the lander could be pegged at between 12 700 and 13 600 kilograms, instead of the 9000 kilograms listed in the proposal.⁵

One early concern, though not directly connected with external design, was the firing of the ascent engine while it was still attached to its launch pad, the descent stage. The exhaust blast in the confined space of the inter-stage structures—called FITH for fire-in-the-hole—could have untoward effects. Some observers feared that the shock of engine ignition might tip the vehicle over. And what would happen if the crew had to abort during descent, shed the descent stage, and return to lunar orbit? This would require extra fuel, posing yet another weight problem. Scale model tests in 1964 allayed these misgivings to some degree, but the real proof had to wait for a firing test in flight of a full-scale vehicle.⁶

Although the descent structure, with its four propellant tanks, appeared practical from the standpoint of weight and operational flexibility, the ascent stage was harder to pin down. Nearly two years passed before the cabin face, windows, cockpit layout, and crew station designs were settled. By late 1963 Grumman engineers had begun to worry about the weight and reliability of the four-tank arrangement, with its complicated propellant system. They recommended changing to a two-tank model, and Houston concurred. Redesign delayed the schedule ten weeks at an added cost of \$2 million, but the system was much simpler, more reliable, and lighter by 45 kilograms. Yet the change brought its own problems. Because oxidizer was heavier than fuel, four tanks had allowed the engineers to put one tank of each on either side of the cabin for balance. With only two tanks, some juggling had to be done to maintain the proper center of gravity. The fuel tank was moved farther outboard than the oxidizer, giving a “puffy-cheeked” or “chipmunk” appearance to the front of the vehicle.⁷

Also shaping the face of the ascent stage were its windows. Windows were basic aids for observation and manual control of the spacecraft, and the pilots expected to use them in picking the landing site, judging when to abort a mission, and guiding the spacecraft during rendezvous and docking with the command module.

The importance of visibility was recognized early in Houston's studies and stressed in Grumman's original proposal. In both, large windows afforded an expansive view. Grumman had featured a spherical cabin like that of a helicopter, with four large windows so the crew could see forward and downward. This design was discarded because large windows would require extremely thick glass and a strengthening of the surrounding struc-

ture. The environmental control system would have trouble maintaining thermal balance. Two smaller windows could replace the four large ones, but the field of view would have to remain very much the same. To get the required visibility with smaller and fewer windows, Grumman had to abandon its spherical cabin design. The new cylindrical cabin had a basically flat forward bulkhead cut away at various planar angles; the large, convex windows gave way to small, flat, triangular panes (about one-tenth of the original window area) canted downward and inward to afford the crew the fullest possible view of the landing area.⁸

Grumman's change to a cylindrical cabin posed another problem. A spherical shape is simple from a manufacturing standpoint, because of the relative ease in welding such a structure. The new window arrangement and front face angularity made an all-welded structure difficult. The Grumman design team wrestled with the new shape and in May 1964 adopted a hybrid approach. Areas of critical structural loads would be welded, but rivets would be used where welding was impractical. Grumman neglected to inform Houston of the switch in manufacturing processes, but a Houston engineer noticed the combination of welding and riveting while on a visit to Bethpage.

Toward the end of May, there was a series of reviews and inspections of Grumman's manufacturing processes. NASA representatives looked at welding criteria, mechanical fastening techniques, and the behavior of sealant compounds under temperature extremes and a pure oxygen atmosphere. The contractor demonstrated that its part-riveted structure showed very low oxygen-leak rates in testing. Although Manned Spacecraft Center officials tentatively approved the change, they left an engineer from the MSC Structures and Mechanics Division in Bethpage to watch Grumman closely. Marshall experts visited Grumman from time to time to extol the virtues of an all-welded design and to warn of the problems of mechanical fabrication. But the peculiarities of the lunar module made a mix of the two techniques almost inevitable.⁹

TAILORING THE COCKPIT

The lunar module's interior was as different from that of other manned spacecraft as its exterior. And it also took two years to design. A home on the moon required some very special features besides visibility: equipment and procedures for rendezvous and docking, environmental control for living, an easy means for leaving and reentering while on the moon, and the capability of operating in a low-gravity or no-gravity environment.¹⁰

With an internal volume of 60 cubic meters, the lunar module would be the largest American spacecraft yet developed. It would also be the most spacious, except for the command module when the pilot was there alone.

CHARIOTS FOR APOLLO

To lessen already formidable crew training demands, Houston pressed Grumman to make the cabin instruments and displays as similar as possible to those of the command module. Complete duplication was impossible, however, because the two craft were so unlike. Ground rules were laid down governing the degree of redundancy required in controls and panels. Although these controls would be duplicated on each side of the cockpit, some of the instrument displays would have to be shared by the crewmen. Above all, Grumman was told, the spacecraft must be designed so that the hover and touchdown could be flown manually and so that no single failure of the controls or displays could cause a mission abort.¹¹

Because the lunar module was a means of transportation, as well as shelter and living quarters for the crew while on the moon, cockpit design presented interesting problems to human factor engineers. The man-machine interface embraced such items as stowage of space suits and personal equipment and room for the pilots to move about within the cabin. In a mockup in mid-1964, two crewmen demonstrated that they could put on and take off their portable life support systems with suits either pressurized or deflated, reach for and attach umbilical hoses, and recharge their backpacks. The MSC Crew Systems Division drew up a document governing spacecraft-spacesuit interface and change procedures. This was used by NASA to supplement spacecraft specifications and interface control documents. It was also an important managerial tool between Grumman and North American and their major associates, MIT and Hamilton Standard (developers of the guidance and navigation system and the life support system).¹²

The astronauts were an essential "subsystem" on the lunar module, and they were very much in evidence at Bethpage, as well as at Downey, where they helped in the design of the command module. Scott Carpenter, Charles Conrad, and Donn F. Eisele drew the lunar module as their special assignment, and William F. Rector, the lunar module project officer, frequently called upon them for help. He also urged other astronauts to take part in the periodic mockup reviews and significant design decisions: "They should be [part] of it," Rector said. "They're going to fly it." This was not an unusual arrangement; astronauts, being both engineers and test pilots, have played an active role in the design and development of every manned American space vehicle.*

Conrad probably worked more on the vehicle's basic design than any other pilot, as the configuration evolved. Rector relied on him to sound out

* An interesting example of pilot preference influencing spacecraft design revolved around including an "eight-ball" (an artificial-horizon instrument used for attitude reference) in the lunar module. Grumman had proposed an eight-ball, assuming that the astronauts would want it. Arnold Whitaker recalled, "The first thing NASA did was to say that there's no operational requirement for it—take it out. So we took it out. Then the astronauts came along and said,

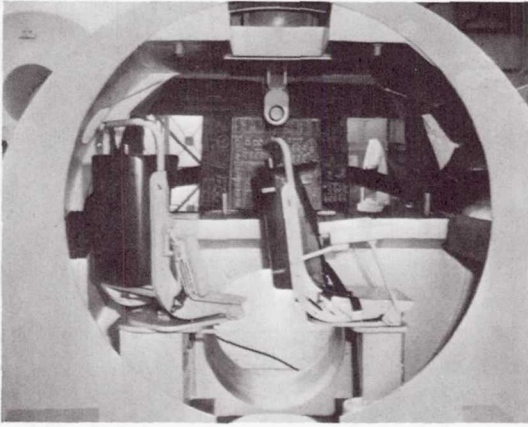
the crews on cockpit features—controls, switch locations, and visibility, among others. One innovation which Grumman favored, and which Conrad was instrumental in getting incorporated, was electroluminescent lighting. An inherent problem in both aircraft and spacecraft had been light intensity that varied from panel to panel. This uneven lighting made it difficult for a pilot to scan his instruments rapidly and to adjust quickly to low-level exterior light conditions. Electroluminescence, a wholly new concept that used phosphors instead of conventional filament bulbs, afforded an evenness in intensities hitherto unequaled in any flying craft. At the same time, it weighed less and used far less power than incandescent lighting. Conrad also got this new system into the Block II command module.¹³

The seating arrangement in the lunar module was perhaps the most radical departure from tradition in tailoring the cockpit. It soon became apparent that seats would be heavy, as well as restrictive for the bulky space suits. Bar stools and metal cagelike structures were also considered and discarded. Then an idea dawned. Why have seats in the lander at all? Its flight would be brief, and the g loads moderate (one g during powered flight and about five on landing). Since human legs were good shock absorbers, why not let the crew fly the lunar module standing up?

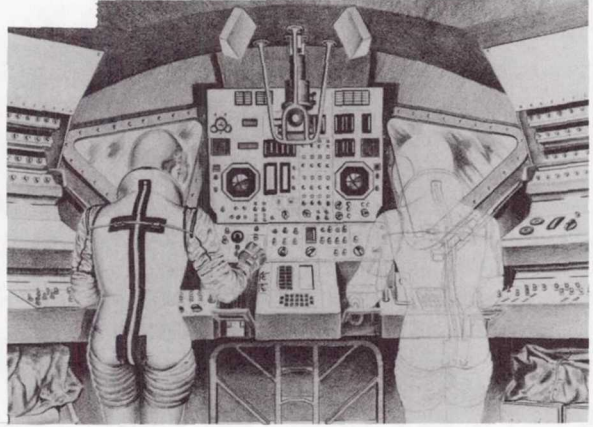
This concept was bandied about rather casually at first by two Houston engineers, George C. Franklin and Louie G. Richard. Franklin then went with Conrad to talk to Howard Sherman and John Rigsby at Bethpage. These Grumman employees, in turn, passed the idea along to Kelly and Robert Mullaney. At this point, the seat and window problems merged. Standing up, the crew would be close enough to the windows to get a larger field of view (one engineer estimated it at 20 times greater) than with any seating arrangement yet suggested. Moreover, since cockpit designers would not have to worry about knee room, the cabin could be shortened, saving 27 kilograms and improving the structure. Conrad called it a "trolley car configuration," and said, "We get much closer to the instruments without our knees getting in the way, and our vision downward toward the moon's surface is greatly improved."

Grumman technicians later devised a restraint system to hold the pilots in place during weightless flight and prevent them from being jostled about the cabin during landing. Resembling the harness used by window washers and linked to a pulley and cable arrangement under constant tension, it was augmented by handholds and arm rests and by Velcro strips to keep the pilots' feet on the floor.¹⁴

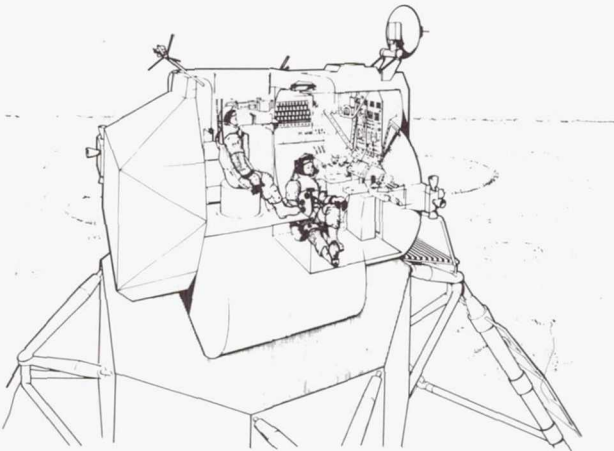
'That's ridiculous. We must have it.' So we put it [back] in. By this time, we're late. Dr. Shea had a program review and said, 'What's holding you up?' And we said, 'This is one of the things. . . .' And he said, 'Take it out. I'll accept the responsibility for it.' The astronauts found out about it and said, 'We won't fly a vehicle until you put it in.' And NASA put it in, this time with a kit [for easy removal later]."



Mockup of lunar module cabin with seats.



NASA engineers in 1964 decided that astronauts could stand in the lunar module cabin during the trip to the lunar surface. Note triangular windows.



Proposed sleeping positions for astronauts on the moon.

HATCHES AND LANDING GEAR

The lander originally had two docking hatches, one at the top center of the cabin and another in the forward position, or nose, of the vehicle, with a tunnel in each location to permit astronauts to crawl from one pressurized vehicle to the other. (Extravehicular transfer between craft remained an emergency backup method.) After injection into a translunar trajectory, a course toward the moon, the command module pilot would turn his ship around, fly up to and dock with the lander's upper hatch, and then back the two vehicles away from the spent S-IVB third stage. This top-to-top docking arrangement aligned the thrust vector of the service module propulsion engine with the centers of gravity of the two spacecraft, thus avoiding adverse torques or tendencies to tumble during firings for mid-course corrections and injection into lunar orbit. The crew would enter the lunar module through this hatch. When the lander returned from the moon,

however, the front hatch would be used for docking and crew transfer. With no windows in the top of the lander, the lunar pilots would be flying blind if they docked with the upper hatch. One of Grumman's human factor experts later said, in an apt analogy, "It's nice to see the garage . . . when you drive into it."¹⁵

By spring 1964, NASA and Grumman engineers were thinking of deleting the front docking procedure and adding a small window above the lunar module commander's head. This overhead window might add seven kilograms weight and some extra thermal burden, but cabin redesign would be minimal. The added weight would be offset by eliminating the front tunnel and the extra structural strength needed to withstand impact loads in two areas. Eliminating forward docking had another advantage. The hatches could now be designed for a single purpose—access to the command module through one hatch and to the lunar surface through the other—which certainly simplified the design of the forward hatch. NASA directed Grumman to remove the forward docking interface but to leave the hatch for the astronauts to use as a door while on the moon.¹⁶

Once the location of the hatches was settled, getting the astronauts out and onto the lunar surface had to be investigated. Using a cable contraption called a "Peter Pan rig" to simulate the moon's gravity, Grumman technicians looked into ways for the crews to lower themselves to the lunar surface and to climb back into the spacecraft. When astronaut Edward White, among others, scrambled around a mockup of the lander, using a block and tackle arrangement and a simple knotted rope, he found that both were impractical. In mid-1964 a porch, or ledge, was installed outside the hatch and a ladder and handrail on the forward landing gear leg. When the astronauts discovered they had trouble squeezing through the round hatch in their pressurized suits and wearing the bulky backpads, the hatch was squared off to permit easier passage.¹⁷

All these design features, although unusual, appeared to be compatible with the lunar environment—at least the engineers did not entertain any special worries. But the landing gear was different. The design of the legs and foot pads depended on assumptions about the nature and characteristics of the lunar surface. In the absence of any firm knowledge and with scientific authorities differing radically in their theories, how should one design legs to support a craft landing on the moon?

Grumman had first considered five legs but, during 1963, decided on four. The change was dictated by the weight-versus-strength tradeoff that had produced the cruciform descent stage, with its four obvious attachment points. The revised gear pattern also greatly simplified the structural mounting of the vehicle within the adapter. Four legs set on the orthogonal axes of the lander (forward, aft, left, and right) mated ideally with the pattern of four reaction control "quads" (the basic four-engine package). The quads were rotated 45 degrees so the downward-thrusting attitude control engine

CHARIOTS FOR APOLLO

fired between the two nearest gear legs, overcoming a severe thermal problem of the five-leg arrangement.¹⁸

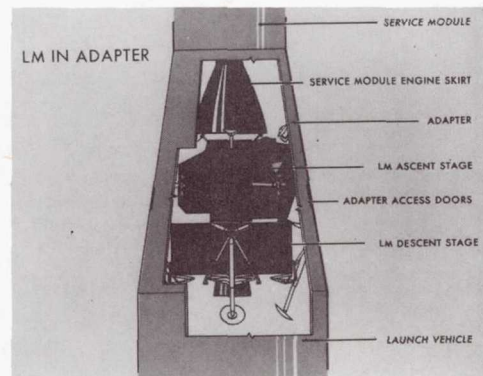
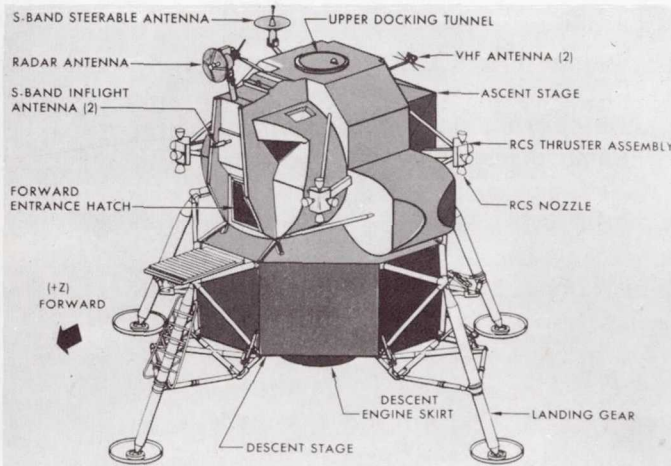
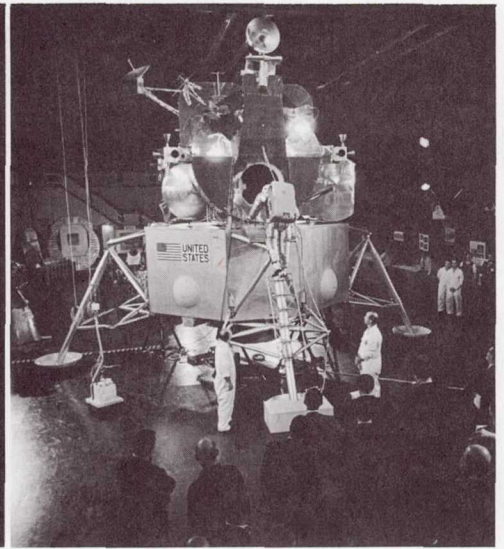
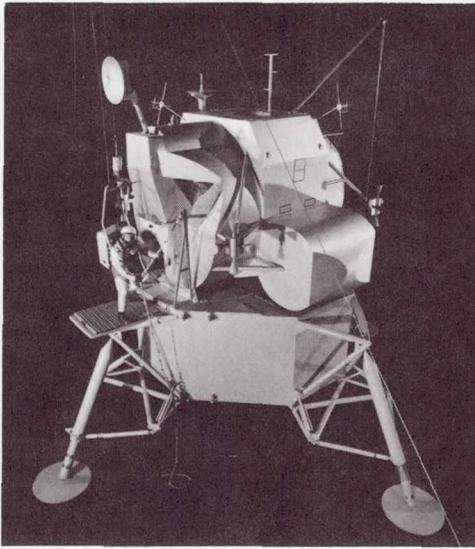
While Bethpage was wrestling with the legs, Houston decided it had been too optimistic about the load-bearing strength of the lunar surface in the request for proposals. The resulting revision placed heavier demands on the landing gear, and Grumman had to enlarge the foot pads from 22 to 91 centimeters in diameter. The bigger feet made the gear too large to fit into the adapter. A retractable gear therefore replaced the simpler fixed-leg gear. Retractability also figured in the shift from five to four legs—the fewer to fold, the better.

Leg experts at Grumman had to change the geometry of the undercarriage, devise the best structure for impact absorption and stability upon landing, and choose the most suitable folding linkages. A broad program of computer-assisted analysis at Houston and Bethpage was used to determine the worst combinations of conditions at impact. The studies were reinforced by drop tests of lander models at Houston, Bethpage, and Langley. There were also plans to drop-test full-sized test articles to check out the new designs.¹⁹

During 1963 Grumman engineers continued to worry about the nature of the lunar surface and to carry on theoretical and simulation studies of lunar geology and soil mechanics, with the support of such consulting firms as the Stevens Institute of Technology in New York and the Arthur D. Little Company in Massachusetts. Much of this work covered the interaction between vehicle and surface at the moment of landing. What would happen to the landing gear at touchdown? Would the lunar dust that might be kicked up by the descent engine exhaust obscure the landing site? Would soil erosion affect the stability of the lander? Washington also assisted in this research. In mid-1963, Bellcomm surveyed all that was being done inside and outside NASA and suggested that a backup gear be developed, in case the surface should be more inhospitable than it appeared.²⁰

But Grumman could not wait on the outcome of these studies. At meetings in Houston in October and November, contractor engineers described gears that tucked sideways (lateral folding) for stowage in the adapter; a tripod arrangement (radial), with three struts meeting at the base just above the footpad, that tucked inward; and a cantilevered device, with secondary struts for extra strength that folded inward against the vehicle for stowage and braced the leg when deployed for landing. Houston and Bethpage selected the cantilevered version. Somewhat narrower than the radial one, it was, in many ways, more stable. It had other advantages: less weight, shorter length for easier stowage, and a simpler, and therefore more reliable, folding mechanism.

A landing gear for the lunar surface had to be designed for varying landing conditions, such as protuberances, depressions, small craters, slopes, and soil-bearing strength. To achieve the necessary stability, the landing



Astronauts found a knotted rope from the lunar module difficult to climb down (or up); the addition of a ladder on a landing gear leg made the task much easier. The drawings show improved lunar module features (left)—ladder, porch, hatch, and rendezvous window (above the triangular window)—and the fit of the LM inside the adapter during launch.

gear had to be able to absorb a diversity of impact loads. Houston and Bethpage met this challenge by using crushable honeycomb material in the struts, so the gear would compress on impact. A principal advantage of honeycomb shock absorbers was their simplicity. Since they had to work only once, the more common hydraulic shock absorbers and their complexities

CHARIOTS FOR APOLLO

could be avoided. Subsequently, crushable honeycomb was also applied to the large saucerlike foot pads to improve stability further for landing.²¹

ENGINES, LARGE AND SMALL

When Grumman began designing the lunar module in January 1963, its major subcontractors began work on the vehicle's integral subsystems: Bell Aerosystems, ascent engine; Rocketdyne Division of North American, descent engine; The Marquardt Corporation, reaction control system; and Hamilton Standard Division of United Aircraft Corporation, environmental control. Identifying rocket engines as the most critical subsystem, Grumman started their development first. The lander had 18 engines: 2 large rockets, one for descent to the moon and another for return to lunar orbit, and 16 small attitude control engines clustered in quads and pointing up, down, left, and right, around the ascent stage.²²

During the spring of 1963, Grumman hired Bell to develop the ascent engine, basing the selection on Bell's experience in Air Force Agena development and hoping that the technology from that program might be applicable to the lunar module. Grumman placed heavy emphasis upon high reliability through simplicity of design, and, in fact, the ascent engine did emerge as the least complicated of the three main engines in the Apollo space vehicle (the descent and service module engines were the other two).^{*} Embodying a pressure-fed fuel system using hypergolic (self-igniting) propellants, the ascent engine was fixed-thrust and nongimbaled, capable of lifting the ascent stage off the moon or aborting a mission should a landing not be feasible.

There was one major concern about the ascent engine, and that was the usual worry about the ablation material burning off too fast and causing damage to the thrust chamber. Some ablative material eroded during firing tests at Bell's plant near Niagara Falls and at the Arnold Engineering Development Center in Tennessee. But this erosion was not severe enough to warrant changes in the combustion chambers. In late 1964, Arnold was also the site of a fire-in-the-hole (FITH) static firing test on a full-scale vehicle to supplement Grumman's previous scale-model test. The FITH flight test had to wait for later trials at White Sands.

^{*} The rocket engine of the ascent stage developed about 15 500 newtons (3500 pounds) of thrust, which produced a velocity of 2000 meters per second from lunar launch to docking. The descent stage, a throttleable engine, reached a maximum of 43 900 newtons (9870 pounds) and operated at a minimum of 4700 newtons (1050 pounds) for delicate maneuvers. Considerably larger than the two lunar module engines, the service module motor attained 91 200 newtons (20 500 pounds) of thrust.

Not everything went well with ascent engine development, however. About a year after the program began, the subsystem manager in Houston discovered that Grumman and Bell were using testing criteria left over from the Air Force Agena program. Since the Agena was unmanned, these were less stringent than NASA demanded for manned spacecraft. More rigorous standards were belatedly imposed by Houston, and a problem was revealed. In "bomb stability" tests, where the engine had to recover from combustion instability caused by an explosive charge within the combustion chamber, the ascent engine "went unstable" (failed to return to normal operation), and structural damage followed. This problem would have to be resolved before the engine could be trusted to bring a crew back from the lunar surface.²³

The lunar module descent engine probably was the biggest challenge and the most outstanding technical development of Apollo. A requirement for a throttleable engine was new to manned spacecraft. Very little advanced research had been done in variable-thrust rocket engines—NASA's principal effort in this field, the hydrogen-fueled RL-10 used in the S-IV stage of the Saturn, antedating work on the lunar module engine by only a few months. Rocketdyne proposed a method known as helium injection, introducing inert gas into the flow of propellants to decrease thrust while maintaining the same flow rate. Although Bethpage and Houston agreed that this seemed a plausible approach to throttleability, it would be a major advance in the state of the art, and the MSC Apollo office directed Grumman to carry out a parallel development program and select the better design.

On 14 March 1963, Grumman held a bidders' conference, attended by representatives from Aerojet-General, Reaction Motors Division of Thiokol, United Technology Center Division of United Aircraft, and Space Technology Laboratories, Inc. (STL). In May, STL (which had lost out in the original bidding for the engine) was selected to develop the competitive motor. STL proposed a pressure-fed hypergolic system that was gimballed as well as throttleable. The engine's mechanical throttling system used flow control valves and a variable-area injector, in much the same manner as does a shower head, to regulate pressure, rate of propellant flow, and the pattern of fuel mixture in the combustion chamber.

With two subsystem contractors working on such radically different throttling techniques, NASA planners, as Rector later said, "thought one or the other would stub his toe real quick . . . , that it would be obvious that we should go one [way] or the other—but it wasn't happening. They were both . . . pretty good. . . ." STL and Rocketdyne continued this head-to-head competition for the final—and lucrative—engine development and qualification contract through the end of 1964."²⁴

In November 1964, Joseph Shea, Apollo spacecraft manager in Houston, told NASA Apollo Program Director Samuel Phillips in Washington that

CHARIOTS FOR APOLLO

he had established a committee* of propulsion experts from Grumman, the Marshall and Lewis centers, NASA Headquarters, and the Air Force to review the contractors' efforts and recommend a choice. Selection of one firm over the other rested with Grumman and MSC, in the final analysis, and, Shea stated, "I do feel that we should have the intelligence at our disposal to appreciate all ramifications of [Grumman's] final recommendation."

Panel members visited both companies the week of 7 December 1964, but their findings were largely inconclusive. The progress of each firm was nearly identical. Both contractors, although experiencing minor troubles with injector designs, demonstrated satisfactory structural compatibility between injector and thrust chamber. After a year and a half, neither helium injection nor mechanical throttling had proved superior over the other. On 5 January 1965, Grumman decided to stick with Rocketdyne.²⁵

Manned Spacecraft Center Director Gilruth appointed a five-member board† to weigh Grumman's recommendations, review the findings of the earlier committee, and study a technical comparison prepared by Houston's Propulsion and Power Division. On 18 January this review board, in a surprising move, reversed Grumman's action and named STL instead of Rocketdyne. The board said that the

recommendation of STL is based upon the assessment that STL is in a more favorable position [and] is capable of supplying more management and superior resources to this program without interference of other similar programs. . . . there are potential benefits to be gained for the Gemini and Apollo attitude engine programs at NAA by the cancellation of the [Rocketdyne] descent engine development.‡

This decision, unusual because Houston rarely vetoed a recommendation for a subcontractor made by a prime contractor, was sustained by Phillips at Headquarters. Shea and Contracting Officer James L. Neal then directed Grumman to proceed with STL.²⁶

Grumman chose Marquardt to build the lunar module's third engine system, the small 100-pound-thrust attitude control thrusters. In 1960, Warren P. Boardman and Maurice Schenk of Marquardt had visited Robert

* Committee members were Max Faget (chairman), Rector, Joseph G. Thibodaux, and C. Harold Lambert (MSC); Charles H. King and Adelbert O. Tischler (NASA Headquarters); Leland F. Belew (Marshall); Irving A. Johnson (Lewis); P. Layton (Princeton University); Major W. R. Moe (Edwards Rocket Research Laboratory, USAF); and Joseph M. Gavin and M. Dandridge (Grumman).

† Members of the Subcontractor Review Board for the LEM Descent Engine were Faget (chairman), Dave W. Lang (Procurement), André J. Meyer, Jr. (Gemini), Joseph G. Thibodaux, Jr. (Propulsion and Power Division), and Rector.

‡ Gemini manager Charles W. Mathews was having trouble getting reliable engines for his spacecraft from Rocketdyne. In its decision, the board was obviously supporting both his program and Apollo.

Piland and Caldwell C. Johnson at Langley to discuss their firm's propulsion work. Piland and Johnson were intrigued with the idea for a bipropellant thruster that promised to be far superior to the monopropellant engine then used in Mercury. Testing of Marquardt's product—a dual-valve, pulse-modulated engine with a radiation-cooled combustion chamber—at the Lewis Research Center paved the way for its incorporation into Apollo. Marquardt at first supplied engines for both the command and service modules. In mid-1962, NASA decided to use the Marquardt engine for the service module only, because the command module thrusters would be buried within the heatshield, making radiation cooling impossible. Rocketdyne would supply the command module thrusters, which were similar to those it was already developing for Gemini.

Marquardt would furnish attitude control engines and mounting structure and perform some tests of the propellant system. Grumman would provide tanks (purchased from Bell), propellant lines, and the pressurization system. Apollo officials had expected that the service module thrusters, with only slight modifications, could also be used in the lander, but common use proved difficult. The end results, though beneficial, fell far short of Houston's anticipations. Differing functional requirements, as well as unique environmental and design constraints, precluded direct incorporation of the service module thruster. Houston, however, complained that Grumman failed to take advantage of all the common-use technology available and attributed delays in procurement of many thruster components to this failure.²⁷

After thruster tests at Bethpage and at Marquardt's Magic Mountain Facility in California during the first half of 1964, a technical problem emerged: the engine spiked, or backfired, at ignition, and a rapid rise in temperature and pressure caused the engine to explode. The spiking appeared so significant that Grumman wanted to develop a backup engine through another source, but Houston refused permission. Marquardt eliminated spiking by installing a small, tubular "precombustion" chamber inside the engine.²⁸

ENVIRONMENT AND ELECTRICITY

Grumman selected Hamilton Standard to supply the environmental control system for the lunar module. Like AiResearch's unit in the command module, it was a "closed-loop" atmospheric circulation system, using supercritical oxygen and nonregenerative removal of carbon dioxide to provide a pure oxygen atmosphere. The system also had a liquid-circulating network and heat-absorbent panels to maintain a comfortable temperature inside the cabin. By mid-1964, Hamilton Standard had finished the design phase and begun fabrication and testing. Occasional problems arose during develop-

CHARIOTS FOR APOLLO

ment, but none that threatened the manufacture of a successful subsystem.²⁹

United Aircraft Corporation's Pratt & Whitney Aircraft Division, a legendary name in aircraft powerplants, was also a pioneer in research on fuel cells using hydrogen and oxygen as reactants to generate electricity. Grumman picked this firm in July 1963 to develop the power system for the lander. The fuel cell program was laden with technical and managerial problems. Many of the lander's components operated with considerable independence, but the electrical power system had a complex interrelation with virtually every subsystem in the vehicle. The question of how many fuel cell stacks and how many tanks of reactant were needed to meet electrical requirements was, therefore, difficult to answer. In March 1964, Houston approved a three-cell, five-tank arrangement; by summer the fuel cell was in deep technical trouble. NASA and Grumman engineers concluded that it might take more than a year to get the cells working with the other systems properly. The lunar module, which had begun development a year late, did not have the time to spare.

Houston told Grumman in late 1964 to consider substituting batteries for fuel cells, and on 26 February 1965 Bethpage was ordered to make the change. Although the switch was not entirely welcome to the lunar module design team, it caused no appreciable delay. And to some it came as a distinct relief; the beauty of batteries lay in their simplicity, hence their reliability, in contrast to fuel cells. Some of the battery development cost would be offset by the cancellation of the Pratt & Whitney contract.³⁰

THE "SUB-PRIME" AND THE RADAR PROBLEM

Grumman contracted with Aerospace Communications and Controls Division of Radio Corporation of America (RCA) in Burlington, Massachusetts, for engineering support, radars, an inflight test system, and components of the stabilization and control system. RCA, the "sub-prime" contractor, was also to design and manufacture ground checkout equipment for these items. Although the two companies had worked together for years, the Grumman-RCA experience with the lunar module was fraught with difficulties. Electronics components became a pacing item in the development of the lander's subsystems, causing unhappiness at NASA Headquarters and culminating in an investigation by the General Accounting Office.³¹

The extremely complex stabilization and control system was the source of much of the trouble. Design had to await definition of mission requirements and planning. To complicate matters further, Grumman did not buy the total system but merely procured parts, through RCA, from Minneapolis-Honeywell, which supplied similar items to North American for the command module. There was some commonality of parts, but the lander hardware had to be repackaged, often causing lengthy delays. Communica-

tions gear was purchased from Collins Radio and Motorola in the same manner. Tiring of this roundabout way of doing business, Houston finally decided to speed things up by supplying the television camera, originally intended for development by RCA, as government-furnished equipment. In mid-1964, the Westinghouse Electric Company was asked to submit a bid for the camera.³²

RCA's role was further cut when inflight maintenance was canceled. At the outset of the program, the crews had been expected to perform basic repairs to electronics equipment in the lander, as well as in the command module, using spare parts stowed aboard the spacecraft. By mid-1963, Houston Flight Operations Director Christopher Kraft was arguing that the crewmen simply would not have time to repair faulty hardware during lunar module operations. Thomas Kelly was convinced that inflight maintenance would degrade reliability instead of improving it. This was probably true, since the electronic spares would be subjected to cabin humidity even when stowed. When George Mueller took over as manned space flight chief in Washington, he also had reservations about the plan. Inflight maintenance was deleted from the program and the crew was to rely on operational displays and the caution and warning system to detect malfunctions. Redundancy would be "wired in," with duplicate or backup components the crew could switch to, and all electronics inside the cabin would be hermetically sealed to protect against moisture and contaminants.³³

Radar, tied into the guidance and navigation system, was one of the hardest pieces of the lunar module to qualify. Two sets would be used, one for landing, the other for rendezvous. Under its blanket subcontract for electronics, RCA was to design the system, manufacture the rendezvous radar, and buy the landing subsystem. After evaluating proposals from four bidders, RCA picked Ryan Aeronautical Company, developer of landing radar for Surveyor.³⁴

Development of the lunar module radar was not expected to be difficult, since no technological breakthrough was demanded for either system. Integrating these sets with the guidance and navigation system, however, was another matter. There were also problems in properly placing and insulating the antennas. Getting the precise ranging accuracy needed and overcoming the weight increases that resulted from meeting these requirements probably posed the biggest problem of all. A happy medium between optimum weight and desired reliability was elusive, and progress was practically nil.

During the final quarter of 1964, the chief of guidance and control in Houston warned Shea that the radar program was having trouble with weight, accuracy, reliability, thermal characteristics, and costs. Shea and William A. Lee, chief of MSC's Apollo Operations Planning Division, began to think about omitting the rendezvous radar from both the command and lunar modules. Lee believed these units were doubly redundant, since

CHARIOTS FOR APOLLO

rendezvous could be performed by the command module pilot with the aid of data relayed by the Manned Space Flight Network. Donald G. Wiseman, an instrumentation and electronics specialist in Houston, thought rendezvous could also be conducted by the lunar module crew, using ground, optical tracking, and S-band and VHF communications equipment ranging information in place of radar. Although not everyone agreed that the system should be eliminated, work was started on the development of an optical tracker.³⁵

GUIDANCE AND NAVIGATION

Guidance and navigation was the most difficult of all the lander's subsystems to develop, both technically and managerially. Development started off simply enough but turned into a complicated tangle. MIT and Houston officials wanted to use the basic command module arrangement in the lander to avoid developing an entirely new system. After Grumman was selected in November 1962, the contractor, the center, and MIT had tried to work out a configuration for the lander. In the middle of 1963, Houston asked Headquarters for permission to procure lunar module guidance through existing agreements with MIT, AC Spark Plug, Kollsman, Raytheon, and Sperry. When Washington refused, time was lost in negotiating new contracts.³⁶

The biggest delay came from a dispute over whether to use the MIT unit in the lunar module. Grumman's refusal to accept MIT's word about the reliability of its system sparked the controversy. Lunar module manager James L. Decker in Houston shared this skepticism and asked Grumman to look into a more advanced system than the three-gimbal platform (pitch, yaw, and roll referencing system) MIT used. Meanwhile, David W. Gilbert, in charge of navigation and guidance in Shea's office, insisted on getting the MIT unit into the lunar module. Grumman was caught between the two opposing factions. Neither of the Houston officials could get the other to change his mind—and the chasm deepened. Top management in Houston and in Washington then stepped in. Bellcomm would study the options, consult with all parties to the argument, and recommend a solution. In due time, NASA decided to stick with MIT and announced its decision, based on Bellcomm's findings, on 18 October 1963.

But the announcement did not completely clear the air, and some rather strained feelings developed between Grumman and MIT. Early in 1964, however, the contractors recognized the necessity of working together on the areas where development progress affected both the lunar module and its guidance system. Set down in formal Interface Control Documents, agreements on these points would govern all future actions by both parties. At the end of February, Rector reported 29 meetings between the contrac-

tors (with 200 more to go, at this rate, he said) and 55 documents drafted, but almost no concessions by either party. In April, Manned Spacecraft Center managers realized that they would have to intervene to break up the logjam. At a two-day meeting in Bethpage on 25 and 26 June, Shea did just that. After scrutinizing the documents, he mediated the differences and forced the contractors to cooperate.³⁷

MOCKUP REVIEWS

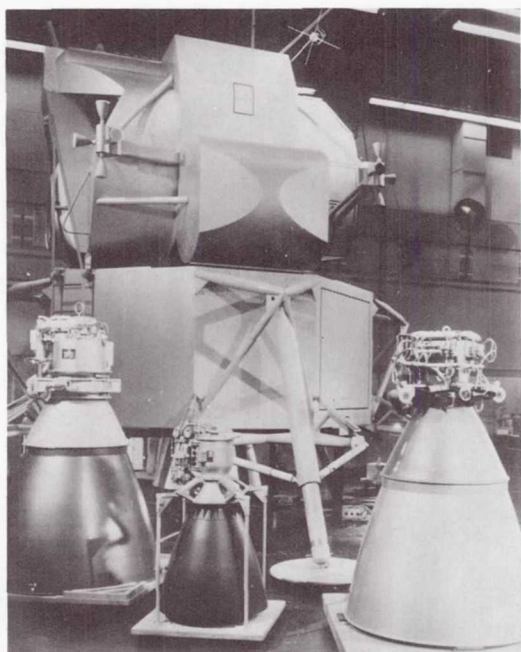
At various stages of lunar module design, mockup reviews were conducted to demonstrate progress and ferret out weaknesses. These inspections were formal occasions, with a board composed of customer and contractor officials and presided over by a chairman from the Apollo office in Houston. Usually present were top management personnel from the NASA Office of Manned Space Flight in Washington and from the field centers, as well as a number of astronauts. The vehicle was thrown open for inspection, and the astronauts were expected to climb in, out, over, and around, to get a feel for the craft.

The first of these reviews, on "M-1" (a wooden mockup of the crew compartment), took place 16-18 September 1963. In general, the cockpit layout was acceptable, although the locations of some equipment and the arrangement of controls and instruments still had to be settled. The astronauts liked the visibility through the triangular, canted windows and the standup crew positions; but they wanted the instrument panel changed so both flight stations would have identical displays.³⁸

About six months later, 24-26 March 1964, Grumman showed its second model, "TM-1," a wooden representation of a complete vehicle. Again attention centered on the cockpit arrangement: support and restraint systems, equipment layout, lighting provisions, location of displays and controls, and general mobility within the cabin and through the hatches. On this occasion, a number of changes were suggested. After evaluation and approval by the review board, these modifications were incorporated into the TM-1 to make up a "design freeze" for constructing an all-metal model, the final review mockup.

TM-1 was far more than just a means to get to the next, more advanced, mockup, however. For several months, Grumman designers used it to study astronaut mobility and spacecraft-spacesuit interfaces. Astronauts and company personnel got into and out of suits inside the cabin, practiced stowing and recharging backpacks, and checked out suit hose connections with the spacecraft's environmental control system.³⁹

The most important mockup review, in October 1964, centered on "M-5"—a remarkably detailed model of a complete spacecraft, including some actual flight equipment inside the cockpit. Even before the inspection,



TM-1 mockup of the lunar module with propulsion system models. The TRW version of the descent engine (left) won the development contract. The model of the ascent engine (center) submitted by Bell Aerospace Corp. subsequently competed with Rocketdyne's version, and both companies later participated in the development.

its prospects for success were discussed in a senior staff meeting at Houston on 2 October. Comparing Grumman's planned M-5 review with a review held a few days before on the Block II command module at North American, which one official considered "a good display for a salesman [but] a poor engineering tool," Max Faget said that, in his opinion, North American representatives should go to Grumman to "see what a mockup should look like." M-5 was the product of two years of configuration studies and the lessons of two previous inspections.

Formal review of M-5 led off with an examination on 5 and 6 October by the astronaut corps. On the following day, MSC Director Gilruth and virtually all the management, engineering, and Apollo leaders from Houston descended on Grumman to inspect the cabin, electrical wiring, plumbing, flight controls, displays, radars, propulsion systems (ascent, descent, and reaction control), environmental control system, communications system, structures and landing gear, and stowage for scientific equipment. No piece of the vehicle escaped the review party's scrutiny and evaluation. The Mock-up Review Board* met on 8 October, examined the 148 proposed changes, and approved 120 of them. These were mostly minor, and none forced any major redesign. M-5 marked the culmination of the configuration definition.⁴⁰

* Board members were Maynard, Rector, Faget, Kraft, and Donald Slayton from Houston and R. W. Carbee and Kelly from Bethpage.

THE LUNAR MODULE AND THE APOLLO PROGRAM

Although configuration was not settled and major subsystems development was not begun until near the end of 1964, NASA had begun taking stock of where the lunar module stood in relation to other pieces of Apollo. Structural connections between the lunar module and other Apollo hardware were confined primarily to the command and service modules and the adapter. Unlike its scratchy relations with MIT, Grumman's association with North American was smooth.* Early meetings between the contractors were devoted to hardware designs and docking requirements. Initially, each manufacturer was to design and test all equipment mounted on his own vehicle, but in March 1963 North American assumed responsibility for the complete docking device as well as the adapter structure.

Late in 1963, design engineers from Downey recommended, and NASA approved, a center probe and drogue for docking. Stowage of the lander in the adapter was settled in October 1963, when the contractors and Houston agreed upon a truncated cone, 8.8 meters long, with the lunar module mounted against the interior wall by a landing-gear outrigger truss. Thereafter, detailed design focused on the dynamic loads expected during launch and on the deployment of the four panels for removal of the lander during flight. Grumman sent North American a mockup to use in confirming the structural mounting and panel opening characteristics.⁴¹

Lunar module ground testing to prove the practicality of the design and flight testing to verify the spaceworthiness of the flight vehicle also had to be worked into overall Apollo plans. Gilruth had stated that one fundamental requirement for mission success was employing "the kind of people who will not permit it to fail." The basic reliability philosophy, he said, was "that every manned spacecraft that leaves the earth . . . shall represent the best that dedicated and inspired men can create. We cannot ask for more; we dare not settle for less." As the lander grew larger and more complex, it became, in the eyes of some observers, the "most critical part of the [Apollo] vehicle." The many things that could doom the crew made ground testing all the more important. Reliability for the lander dictated either redundant systems or, where that was impractical because of weight and size, ample margins of safety.

Grumman's basic plan for ground testing, set forth in May 1963, called for extensive use of test models and lunar test articles (called "TMs" and "LTAs" by the engineers), as well as for propulsion rigs to test propellant lines and for engine firing programs. Because the lander's flight would be

* The two contractors had worked together amicably enough on the Project Christmas Present Report (detailed vehicle test plan), led by North American, and on the Apollo Mission Planning Task Force, headed by Grumman. Both are discussed in Chapter 5.

CHARIOTS FOR APOLLO

brief, Bethpage engineers adopted a practice of testing hardware until it failed, to provide an indication of strength and to gather information on failure points. Ground testing began with individual parts and subsystems and progressed upward, before the spacecraft was committed to flight.⁴²

Bethpage came up with a scheme for testing the lander in simulated flight by powering the vehicle with six jet engines, to overcome the pull of gravity, and using a modified descent engine to practice maneuvering the vehicle. Although the idea appeared workable, it would be both costly and complex. There were also suggestions for swinging the lander from a gantrylike frame at Langley or from a helicopter or a blimp at White Sands. After a second look, the last two were also scrapped. Grumman and Houston hoped that the lunar landing training vehicle being developed by Bell could test some of the flight components at least, but installing extra equipment might slow the development of the training vehicle. A few flight instruments and the hand controller might be incorporated at a later date into the training vehicle, which the astronauts would use to practice simulated lunar landings. Flight testing within the earth's atmosphere was finally ruled out when Langley discovered in wind tunnel investigations that the Little Joe II-lander combination would be aerodynamically unstable.⁴³

Grumman had wanted some unmanned missions, using the Little Joe II and the Saturn IB launch vehicles, before men flew the lunar lander. Houston authorized the procurement of autopilots for unmanned spacecraft but did not actually schedule any such flights. After Mueller invoked the all-up concept, with each flight groomed as though it were the ultimate mission, Houston planners began to think about putting both the lander and the North American spacecraft aboard a single Saturn IB. One Houston engineer even went to Huntsville to ask von Braun about the possibility of increasing the launch vehicle's payload capacity. And there was some discussion about strapping Minuteman missile solid-fueled rocket stages onto the launch vehicle to provide the extra boost needed!

In the meantime, ground testing would have to carry the burden of qualifying the lander until the Saturn was ready to fly the vehicle, which caused some realignment of the lunar module program. Eleven flight vehicles and two flight test articles were earmarked for Saturn development flights. NASA also decided that the first three flight vehicles must be able to fly either manned or unmanned.⁴⁴

In November 1964, Shea, Mueller, and Phillips decided on a tentative flight schedule. Saturn IB missions 201, 202, 204, and 205 would be Block I command module flights. There was no assignment for 203 at this time. Shea told the Houston senior staff that it looked as though an unmanned lander might be flown on 206. The first flight of a combined Block II command module and lunar module would be Mission 207 in July 1967. By that time, the Saturn V was expected to be ready to take over the job of flying the missions.⁴⁵

The lunar module had to be worked into Apollo facilities, as well as into flight schedules. Grumman had its own testing equipment in Bethpage and on the Peconic River, both on Long Island. But the lander's propulsion systems would have to be tested at the Air Force's Arnold Center and at White Sands. Fitting the lunar module into the launch complex at the Cape raised some interesting issues. One of the earliest was the rule that any vehicle flown from there must carry a destruct mechanism, in case a mission had to be aborted shortly after launch. The rule was based on a philosophy that it was better to explode propellants in the air than to have them burst into flame on the ground. Houston, however, refused to put a destruct button in the vehicle that was intended to land men on the moon, with the gruesome possibilities of a malfunction on the lunar surface that would either kill the astronauts outright or leave them stranded. Eventually, the Air Force Range Safety Officer agreed to drop this requirement for the lander.⁴⁶

A difficult task at all locations, Bethpage included, was getting ground support equipment (GSE) ready to check out the lunar module subsystems. Traditionally, GSE has been a problem, since it cannot be designed and built until the spacecraft design is fairly firm. Because the lander was the first of its kind and changed from day to day as the mission requirements changed, Grumman was even slower than other contractors in getting its checkout equipment on the line. Shea complained that "the entire GSE picture at Grumman looks quite gloomy." He insisted that Grumman use some equipment that North American had developed for the command module. The situation had improved by the end of 1964, but much work was yet to be done over the next two years before the equipment could be considered satisfactory.⁴⁷

By mid-1964, both the lander and the command module were beginning to experience the weight growth that seems inevitable in spacecraft development programs. Von Braun promised Mueller in May that he would try to get an extra 2000 kilograms of weight-lifting capability from the Saturn V, which eased some of the pressure on Gilruth's team in Houston. Even so, the lander was getting dangerously fat, moving steadily toward its top limit of 13 300 kilograms. Most of the weight-reducing talent in Houston was busy with the command module, whose Block II configuration was not as well defined at the time as the lander's. Several modifications in the landing vehicle were suggested, but any that limited either operational flexibility or reliability were resisted. Moreover, the lander was so unlike other spacecraft that projections were almost useless in estimating future weight increases. Containing this growth would be a major project during the coming year.⁴⁸

The years 1963 and 1964 had seen the lunar module move from the drawing boards to the manufacturing line. During 1965, hardware fabrication, assembly, and testing would begin. After that, it would take only a

CHARIOTS FOR APOLLO

few steps to put the craft into space. These steps, though few after the spacecraft design had been “frozen,” would not be easy ones. There proved to be several more pitfalls to overcome. Some of these problems—difficulty with combustion in the ascent propulsion system, for example—were resolved only a short time before the mission that fulfilled Apollo’s goal of landing men on the moon.

7

Searching for Order

1965

For the most part, 1965 was a good year for manned space flight. Gemini astronauts flew five missions, all successful, one lasting two weeks and including the world's first rendezvous in space. A series of unmanned flights banished many old specters of doom: three Pegasus satellites proved micro-meteoroids were not as hazardous in near-earth space as some had prophesied, and two Ranger spacecraft, before crashing on the moon, sent back pictures that gave some assurance that Surveyor and Apollo could safely fly to and land on the lunar surface. Apollo's eventual success seemed certain, but first all its far-flung pieces had to be brought together in some semblance of order. For Apollo, therefore, 1965 was a trying, yet fruitful, year.

PROGRAM DIRECTION AND THE COMMAND MODULE

Administrator James Webb knew that the futures of NASA and Apollo were interlocked and that the agency's peak in appropriations and manpower would probably be reached in 1965 and 1966. But neither he nor the other NASA officials who spent six months each year justifying financial needs before the Bureau of the Budget and Congress could predict just when funding requirements would taper off. On one hand, only \$5.1 billion of the \$5.25 billion authorized for fiscal 1965 had been spent; on the other, there were indications that the \$5.2 billion in the fiscal year 1966 authorization might not be enough. Apollo funding was more than \$2.5 billion in

CHARIOTS FOR APOLLO

1965 and would exceed \$3 billion in each of the next few years. The spacecraft alone accounted for a third of this, \$1 billion a year.¹

Almost as soon as he joined NASA, Associate Administrator for Manned Space Flight George Mueller had argued before Congress, the budget bureau, and his superiors that cost and schedule factors were intertwined: slowing the pace—and many asked, why the hurry?—meant stretching both time and payrolls. To hold costs down, Mueller believed in pushing, although not sacrificing, performance, reliability, and quality, continually admonishing his field centers to “get today’s work done today—and some of tomorrow’s work also.” But the drive for order needed more than Mueller’s prompting. On 15 January 1965, Apollo Program Director Samuel Phillips issued an “Apollo Program Development Plan.” Besides serving as a general reference, this document, in its 17 subdivisions, specified how the Apollo objectives would be reached, how performance and proposed changes would be evaluated, and how these changes, after approval, would be implemented. Its first section, Program Management, laid out the responsibilities for all participants in a pie-shaped chart, sliced to show each major piece of the program and the organization—industry or NASA (MSC, Marshall, Goddard, Kennedy, or Headquarters)—assigned to implement these duties. Other sections dealt with such items as scheduling, procurement, data management, configuration management, logistics, facilities, funds and manpower, and systems engineering. This directive pulled together, in one place, all the parts of Apollo and explained how the decisions to integrate them would be made.²

Mueller had revived the dormant Panel Review Board in late 1964,* hoping to get a tighter rein on configuration control management of the spacecraft and launch vehicles and to speed up the manufacture and qualification of flight vehicles. Houston had established a Configuration Control Panel in 1963, but spacecraft development was in such a fluid state that panel authority was limited. By late 1964, however, ASPO Manager Joseph Shea was able to set up a stronger, more effective, Configuration Control Board to review and manage changes in the spacecraft.³

After much correspondence between Washington and Houston, Shea issued a Configuration Management Plan, outlining his board’s responsibilities and limitations and the functions of each of the program offices under his jurisdiction in carrying out the dictates of the board. But having a plan did not immediately turn the tide. Even after the document was published, Shea and his lieutenants tried in vain to stem mounting weights and slipping schedules. During a briefing at North American in April, Shea felt, as he had earlier, that engineering was getting out of hand and slowing

* See Chapter 5. Members of the review board were Mueller and Phillips (NASA Headquarters), George Low (Houston), Eberhard Rees (Marshall), and Rocco Petrone (Kennedy).

SEARCHING FOR ORDER

progress on both Block I (earth-orbital) and Block II (lunar-orbital) command modules. Block I spacecraft 004 and 007 would be three and six weeks late leaving the factory, and North American had completed only 526 of nearly 4000 engineering drawings for Block II. Dale D. Myers, NAA Apollo Program Director in Downey, assured Shea that the company was beginning to catch up on its workload. Nevertheless, Myers reorganized his engineering department into six divisions reporting to his chief engineer, H. Gary Osbon: systems engineering (under Norman J. Ryker, Jr.), project engineering (Ray W. Pyle), vehicle systems (J. J. Williams), control systems (S. M. Treman), ground support equipment (D. K. Bailey), and planning and operations (C. V. Mills).⁴

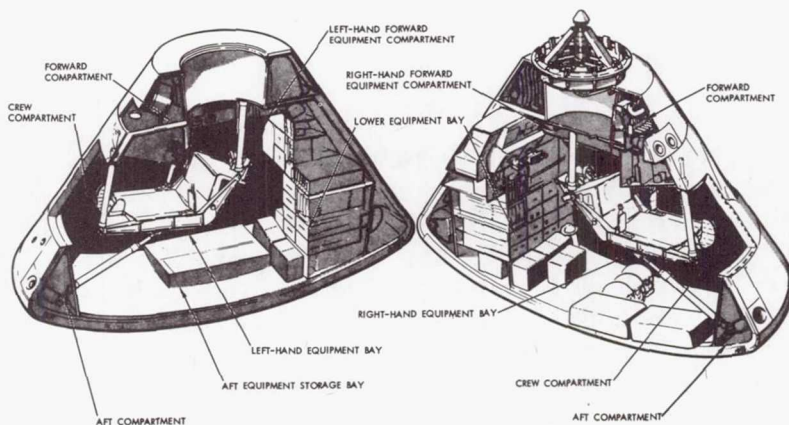
Configuration control was a major factor in bringing order to Apollo, but there had to be some way to gauge how well it worked. In mid-August, Mueller and Phillips identified a series of reviews, inspections, and certifications that would be key checkpoints for Apollo:

1. Preliminary Design Review (PDR)—to review the basic design during the detailed design phase;
2. Critical Design Review (CDR)—to check specifications and engineering drawings before their release for manufacture;
3. Flight Article Configuration Inspection (FACI)—to compare hardware with specifications and drawings and to validate acceptance testing (FACI could be repeated to make sure that any deficiencies had been corrected; it would also be repeated on every vehicle that departed significantly from the basic design);
4. Certification of Flight Worthiness (COFW)—to certify completion and flight-qualification of each vehicle stage or spacecraft module;
5. Design Certification Review (DCR)*—to verify the airworthiness and safety of each spacecraft and launch vehicle design (DCRs would include all government and contractor agencies with major parts of the programs and would formally review the development and qualification of all stages, modules, and subsystems);
6. Flight Readiness Review (FRR)—a two-part review before each flight, held by the mission director in Washington, to confirm the readiness of hardware and facilities (the mission period would then begin with the commitment of support forces around the world).

These six checkpoints charted the course for the step-by-step flow of hardware from drawing board and shop floor to flight-ready vehicles at the launch site.⁵

While Headquarters was working on configuration control and the review plans, command module weight kept getting out of hand. Caldwell

* The first DCR had been conducted on *Gemini III* on a one-time basis; Mueller was so impressed with the results that he continued the practice for all future missions.



Cutaway views show the interior of the command module (for clarity, the center couch is not shown).

Johnson reminded Max Faget in August that, more than a year and a half earlier, he had pointed to weight control as the single most difficult technical problem. To “keep [the] spacecraft on its diet,” Johnson proposed putting pressure on the subsystem managers to begin a rigorous system of checks and cross-checks down through the subsystem level. Faget passed Johnson’s suggestions along to Shea, who, already aware that he had a fat spacecraft, was also being bombarded with warnings about the lack of reliability in Block I. Owen G. Morris, Shea’s Chief of Reliability and Quality Assurance, listed 71 possible failure points that North American had evidently done nothing to eliminate. Morris was not the only one to raise the reliability issue. Shea’s old adversary in the mode selection, Nicholas Golovin of the President’s Science Advisory Committee, wrote that he had heard of 50 items that accounted for “perhaps 95 percent of the unreliability of the Apollo system.”⁶

Not all the story was bleak, however. In November attention centered on a three-week Critical Design Review for the Block II command module. This event followed reviews of the lower equipment bay and upper deck in February; the guidance and control systems, crew compartment, and docking system in March; the extravehicular mobility unit in April; internal lighting displays and side access hatch in June; and the spacecraft–lunar module adapter in June and August. The major result of all these reviews was an entirely new inspection article called, in engineering shorthand, “EM³” (for engineering manufacturing module mockup), which demonstrated that North American was making progress toward a finished Block II design.

Alan Kehlet, North American’s Block II project manager, and assistants Gerald R. Fagan and Louis W. Walkover made the contractor’s presentation. Kehlet explained that the Critical Design Review was a formal, technical review of the Block II spacecraft as reflected in the program specification. The general format of the briefing was: “This is what the spec says

it's supposed to look like or supposed to do from a functional standpoint, and this is what the design is."

Before Fagan and Walkover launched into discussions of each individual system, Kehlet told his listeners that NASA must shoulder some of the blame for schedule slips at North American:

This is the status of our vehicles in manufacturing. . . . You can see we are about four weeks behind in 2TV-1 [the Block II thermal-vacuum test article] and primarily [because of a] lack of secondary bond details. . . . The reason we're having trouble with secondary bond details is [that] we are having trouble defining the wire routing in certain areas. The reason we're having trouble with defining the wire routing is because the schematics came out late. And the reason schematics came out late was somebody didn't define their system. And NASA and the [North American] project office get blamed for that. So it's a chain event. . . .⁷

For several months, Shea had been critical of Block II progress. He had complained in June that engineers, besides trying to develop the spacecraft, had adopted a stance of "as long as we are making the necessary changes, we might as well introduce these [others]." Therefore he asked the subsystem managers in Houston and Downey, who were causing some of the problems, to review both Blocks I and II and eliminate any unnecessary changes. There were plenty of subsystem or component problems to wrestle with, Shea knew, without constantly redesigning the lower equipment bay to fit changing components. In all fairness, however—and Shea knew this—the subsystem managers at North American and the Manned Spacecraft Center were caught in the trap of changing concepts. For example, the cancellation of onboard maintenance in favor of redundant or backup systems in the event of a malfunction resulted in modified parts and subsystems that would no longer fit in the equipment section.⁸

But sometimes a change was dictated by troubles that cropped up in supposedly uncomplicated areas. One such nagging problem that arose in 1965 was how to keep the command module windows clean. A fiber glass cap with a cork ablator, called a boost protective cover, was attached to the escape tower and fitted atop the spacecraft to protect the windows during tower jettisoning. When tests showed that the cover would crack and the plumes from the escape tower would deposit soot on the windows and possibly cause other damage, North American bonded Nomex (a nylon material strengthened with Teflon) between the fiber glass and cork layers of the cover to reinforce it.⁹

And in areas where problems were expected to arise, they did. Two of the tanks—one holding oxidizer and propellant for the command and service module's reaction control thrusters (with which the spacecraft was steered) and the other housing reactants for the fuel cells that provided electrical

CHARIOTS FOR APOLLO

power—were in trouble. The Bell Aerospace Systems Company furnished North American with “positive expulsion RCS tanks,” a system that forced propellant and oxidizer into the firing chambers where the fluids would ignite on contact. The oxidizer tanks kept failing, and Bell kept trying to fix them in an apparently disorganized manner. Eventually, the trouble was traced to the oxidizer, which had too little nitrous oxide in the nitrogen tetroxide, causing stress corrosion (or cracking) in the tanks. When the nitrous oxide was more carefully specified and controlled, the tanks stopped failing. The hydrogen and oxygen fuel-cell-reactant storage tanks, tucked in a service module bay, were also developing cracks. By August, Shea was worrying whether Beech Aircraft, who supplied them, would be able to diagnose and solve the problem in time for the early flights. With the aid of Langley Research Center, the trouble was traced to a reaction of the nitrogen tetroxide to the titanium used for the oxidizer tanks and tubing. Beech simply installed stainless steel components, and the problem ended.¹⁰

Shea found that the penchant for unnecessary changes in Block II was shared by some of the guidance and navigation system developers. On a visit to Honeywell in May 1965, he learned that 50 percent of the stabilization and control circuitry was new, 30 percent was slightly modified, and only 20 percent was identical with Block I wiring. Although he conceded that many of the changes were warranted, Block II had been used to justify nonessential circuits, as well. Shea believed that the Apollo office was inviting trouble; the changes had reached a point where more time would be lost in trying to eliminate them. Pressure was applied to make sure that North American kept its associate contractors on both the spacecraft and guidance and navigation systems up to date on changes; interface control documents would be used to prevent this kind of problem in the future.¹¹

LUNAR MODULE REFINEMENT

Lunar module activities also focused on configuration control, schedules, and funds in 1965. J. Thomas Markley, program control chief, directed the Apollo engineers to be more conservative in their proposals to the Configuration Control Panels. Changes in the spacecraft must correct design flaws, not improve hardware. But stemming the flow of changes in the lunar module was not an easy matter; many were required because of its mission.¹²

An example was the installation of frangible probes on the base of each foot pad to tell the crew the lander was a meter and a half above the surface and to switch off the descent motor. If the motor were still firing when the craft touched down, the engine nozzle would be damaged, landing stability might be affected, and the ascent stage might be impaired by debris kicked up by the engine exhaust.¹³

One configuration issue, a carry-over from 1963–1964, remained un-

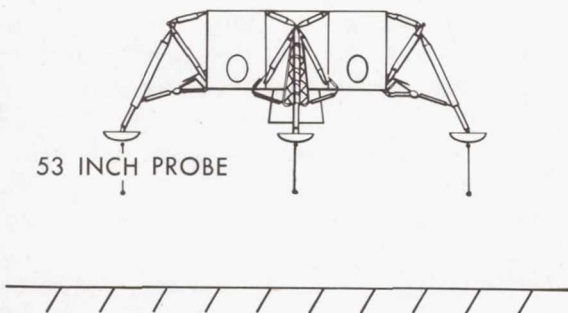
SEARCHING FOR ORDER

resolved throughout 1965—whether to substitute an optical tracking system for the complex, heavy, and expensive rendezvous radar. In February 1965, the Configuration Control Board deleted the radar from the command module and added flashing lights to the lander. If the lone crewman in the command ship had to perform the rendezvous, he would use onboard optics, a ranging capability, and the VHF communications link between the spacecraft, which would also act as backups if the lander's radar failed.¹⁴

In mid-March, Cline W. Frasier of the Guidance and Control Division suggested replacing the rendezvous radar in the lander with an optical system, as well. Consisting of a star tracker in the lunar module, a xenon strobe light on the command module, and a hand-held sextant for the lander's pilot, the substitute would offer two advantages: a weight reduction of 40 kilograms and a cost saving of \$30 million.¹⁵

The Apollo office, hesitant to take such a step, decided to pursue parallel development. In mid-April, Grumman was instructed to design the lander to accept either system and to slow down RCA's radar development program. Radar-tracker studies at the Manned Spacecraft Center would be completed by September, and a contractor would be selected to design the tracker. William A. Lee in Shea's office protested holding back RCA; the delay would force the deletion of the radar from the first and second landers, to be used on earth-orbital missions. This, said Lee, would be a violation of the all-up concept of flying only complete spacecraft. Changes in the radar program would be justified, he concluded, solely

by the implicit assumption that we will cancel the program eventually. The logic of this is very questionable, since it clearly says that the money being spent on this program is being wasted deliberately. We should either pursue the radar in a manner which would permit its use on the LEM, or we should cancel it. I can find no middle ground. . . . The small number of earth-orbital LEM flights can be justified only if we adhere rigorously to the ground rules of all-up flights and qualification prior to flight. It is too early in the LEM program to consider compromising these requirements, and to do so for budgetary reasons will almost certainly prove to be false economy.¹⁶



Probe sensor on lunar module landing gear, to alert astronauts that touchdown on the lunar surface was imminent.

CHARIOTS FOR APOLLO

In August, Houston amended its contract with AC Electronics to include the optical tracker as government-furnished equipment. Grumman grumbled but kept the spacecraft design flexible. Two months later, MSC's Assistant Director for Flight Crew Operations Donald Slayton objected to the tracker because of its limitations in determining range and range-rate (approaching and departing speeds) data and the lack of experience in using the instruments. If an immediate choice had to be made, Slayton said, choose the radar. At the end of the year, Mueller, Shea, and Robert C. Duncan set up what they called a "rendezvous sensor olympics" to be completed in the spring of 1966. If either system lagged, the decision would be obvious; if both were successful, Duncan's division would recommend a choice; if both failed, there would be a lot of work ahead.¹⁷

The optical tracker's lighter weight was attractive, since weight was an important factor in 1965. The lander had gained even more weight during the early months of the year than the command and service modules. In May, Shea persuaded Mueller to approve an increase in lander weight to 14 850 kilograms, including crew and equipment. In June, Harry L. Reynolds warned Owen Maynard that it would be difficult to keep the spacecraft below even that figure. All that summer, the warnings continued. Caldwell Johnson wrote Shea in August that the lander might get too heavy to do its job. The next month Shea asked Houston management for help in solving the problem. He also formed a Weight Control Board (headed by himself) to act on reduction proposals.¹⁸

Really worried now, Grumman launched a two-pronged attack known as "Scrape" and "SWIP." Scrape meant just what the word implies, searching the structure for every chance to shave bulk off structural members. But SWIP (Super Weight Improvement Program) was Grumman's real war against weight.

Grumman project engineer Thomas J. Kelly led a SWIP team of a dozen experts in structures, mass property, thermodynamics, and electronics, whose task was to second-guess the whole design. This same team had recently and successfully shaved weight off the F-111B aircraft, and it knew what a tough job it was up against. When the SWIP campaign started, the engineering design was 95 percent complete. So designers pored over already approved drawings, looking for ways to lighten the craft. Grumman also pressured Houston officials to keep all government-furnished equipment for the lander within the specified weights. And Bethpage scrutinized parts supplied by its subcontractors and insisted that these weights be reduced wherever possible. Weekly reports and monthly meetings between Bethpage and Houston turned into forums for airing suggestions for further reductions and discussions of what had been done. The first such review, held at Grumman on 3 September, revealed that 45 kilograms had already been whittled from the structure by Scrape. The more extensive SWIP plan was outlined—what had been started, what was planned, and what

would be expected by way of evaluation and cooperation from Houston's Apollo subsystem managers.¹⁹

By the end of 1965, Scrape and SWIP had pruned away 1100 kilograms, providing a comfortable margin below the control weight limit. One of the more striking changes to come from this drive for a lighter spacecraft was the substitution of aluminum-mylar foil thermal blankets for rigid heatshields. The gold wrapping characteristic of the lander's exterior saved 50 kilograms.²⁰

Many of these weight-reducing changes made the lander so difficult to fabricate, so fragile and vulnerable to damage, that it demanded great care and skill by assembly and checkout technicians. Structural components took on strange and complex shapes, requiring careful machining to remove any excess metal—a costly and time-consuming process even after vendors had been found who would make these odd looking parts.*²¹

THE LEM TEST PROGRAM: A PACING ITEM

Houston reviewed Grumman's testing program during 1965 to make sure it covered everything from small components to the big test articles. On 15 April Grumman began test-firing the ascent engine at White Sands. Propulsion testing was also being conducted at Bell and STL. Although engine firing programs were behind schedule, Houston expected better performance shortly.²²

Six lunar test articles (LTAs) formed the backbone of the ground test program. Bethpage shipped LTA-2 to Huntsville for vibration testing to see if it could withstand launch pressures, and LTA-10 to Tulsa, to check its fit in the adapter. LTA-1 was a "house" spacecraft, used to iron out problems during fabrication, assembly, and checkout. Three more LTAs were under construction: LTA-8 for thermal-vacuum testing in Houston and LTAs 3 and 5 for combined structural shakings, vibrations, and engine firings.²³

Flight test plans for the early production landers were flexible to accommodate schedule differences with the command module. LEM-1 naturally received the lion's share of attention, since Grumman had to get it ready for an unmanned "LEM-alone" mission (Apollo-Saturn 206A). LEM-1 would have to be ready at least three months before the Block II

* Arnold Whitaker described how the fabrication group was caught in the squeeze between manufacturing requirements and schedule pressures. At a program management meeting he said that "one of the fellows in manufacturing came in [with] a light cardboard box. . . . He said, 'I'll show you why everything's late.' And he dumped out a whole box of machined parts . . . , very complex fittings [too thin to be even] reasonably heavy sheet metal—but it wasn't any sheet metal, it was a complex machined fitting. And he said 'Man, we never built parts like this before in any quantity like this and every fitting on the LEM looks like this.' "

CHARIOTS FOR APOLLO

command module, however, or its first mission would be part of a test of the combined spacecraft.²⁴

But Grumman was moving slowly. In the spring of 1965, John H. Disher of NASA's Washington Apollo office told Shea he believed LEM-1 would be a year late, making the lander a pacing item. Many factors contributed to LEM-1's inertia, but ground testing topped the list. And the trouble in ground testing was getting equipment ready to make the tests. Grumman's old bugaboo—ground support equipment (GSE)—had reared its ugly head. The significance of GSE shortages was not lost on Washington. At a program review on 20 April, Mueller told Houston managers to identify all lander GSE, along with the date it would be needed, as "sort of a thermometer" to bring the weaknesses in the system to Grumman management's attention.²⁵

In mid-May, Grumman officials looked at possible launch dates for the first vehicle but could decide nothing definite because of a pinch in fiscal year 1966 funding. Hardware production had to be cut back in an attempt to absorb some of the loss. In July, Houston directed Bethpage to delete LTA-4, a vibration test article, and two flight test articles (FTAs). To replace the FTAs, two LTAs would be refurbished when they finished ground tests. After trials with scale and full-sized models had been run at Langley and elsewhere, Houston also canceled a landing gear test model as an unnecessary expense.²⁶

Grumman, at a program review on 6 July, then asked NASA to relax the rules on qualification testing and to permit delivery to the Cape of vehicles not fully equipped. Shea rejected this suggestion, ordering his subsystem managers to make sure that only all-up landers left the Grumman plant. Problems with some of the subsystems were a factor in this request. Bell in particular was having trouble with the redesigned injectors and tank bladders for the ascent engine, and manufacturing problems were harassing Hamilton Standard's environmental control system. Subsystem manager Richard E. Mayo asked Donald Sullivan (head of a manufacturing unit in the Apollo office) to find out what was wrong. When he visited the Windsor Locks plant, Sullivan noted that, although Hamilton Standard was turning out high-quality parts, good solid management in assembling and integrating the system was lacking.²⁷

Electrical and electronics gear, where design changes persisted throughout 1965, was also lagging. The abort sensor assembly (part of the abort guidance system), for example, was redesigned to incorporate continuous thermal control, a programmable memory for the computer, and a data-entry-display assembly. In mid-August R. Wayne Young, who had succeeded William Rector as the lander's project officer, ordered Grumman project manager Robert Mullaney to stop making changes if the present system could do the job.²⁸

Program spending began to equal schedules in importance. Just as the lander got rolling toward flight hardware production, it was caught in the

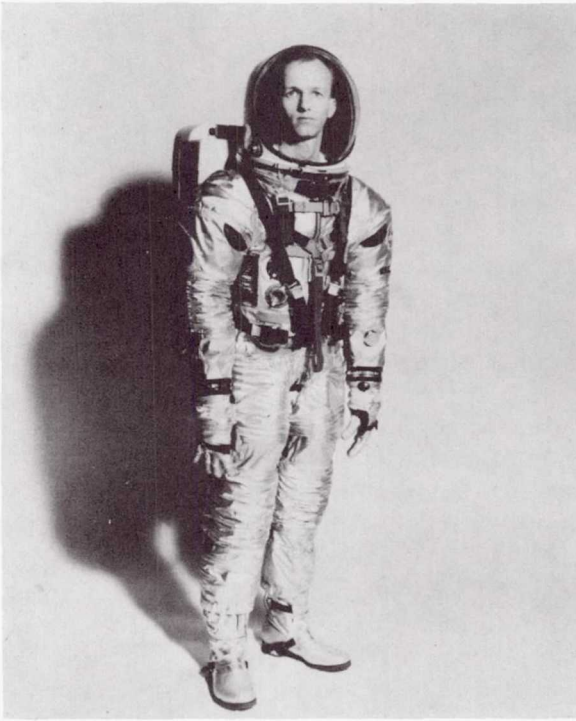
budgetary squeeze imposed by Congress. Grumman had to shoulder most of the burden in holding expenses down. Expenditures had risen dramatically—from \$135 million in fiscal 1964 to an estimated \$350 million for 1966—as Apollo funding reached its crisis during spring and summer 1965. Grumman's fiscal discipline lagged in technical problem-solving, subcontracting, and cost and schedule performance. To push the contractor toward a solution, Houston decided it was time to convert Grumman's cost-plus-fixed-fee contract to an incentive agreement. With incentives to meet and penalties to face if they were not met, Grumman could be expected to overcome these deficiencies.²⁹

The drive for incentive contracting had started in Washington in 1962, when NASA Associate Administrator Robert Seamans and John H. Rubel of the Department of Defense discussed the possibility of converting NASA contracts; defense procurement had called for incentive contracting, whenever possible, for some time. The use of incentives rather than a fixed fee, a turnabout in government dealings with industry, was controversial. Critics pointed to lengthy delays in negotiations that tied up engineers who otherwise could be working on program hardware and a "worsening of government-industry relations by causing contractual bickering." Seamans and Mueller disagreed, insisting that incentives placed more responsibility on the contractor. It did take time and talent to work out the provisions, but it promised better performance.³⁰

NASA had made only modest headway in this conversion during 1963 and 1964, but the agency intended to revamp the spacecraft contracts in 1965. Mueller wrote MSC Director Gilruth in April, stressing that incentives must reflect schedules, cost, and performance, in that order. To pave the way for incentive negotiations, Houston had to clear up a number of unresolved contract change authorizations, which would be reviewed by a board made up of Houston and Bethpage officials. The review began in mid-March and ended in April with participants deadlocked.³¹

Houston and Bethpage kept trying to work out the individual contract changes, but there was still no agreement in early June, after three weeks of negotiations. Gilruth and Shea then discussed the impasse with E. Clinton Towl, president of Grumman, and decided that it was pointless to convert the contract at that time. Houston did impose a LEM Management Plan on Grumman, hoping to control cost, schedules, and performance. Until the last quarter of the year, Grumman would be allowed to spend only \$78 million, which was less than the contract costs estimated during the unsuccessful review. If Grumman could stay within this limit for a quarter, however, negotiations for the incentive contract could resume.³²

In the interval Grumman concentrated on bringing its subcontractors into line and converting its agreements with them into incentive contracts, trying to demonstrate satisfactory control of the program. In September, Grumman submitted a proposal for contract conversion to NASA. Negotia-



The 1965 version of the Apollo spacesuit and backpack. Changes were made before man eventually stepped out of the spacecraft onto the lunar surface.

tions lasted until December and culminated in a contract with enough incentives to spur the contractor to maintain costs and schedules and to meet performance milestones. This arrangement, announced in February 1966, carried the lander program through 1969 at a cost of \$1.42 billion. North American's incentive contract was also negotiated (at an estimated \$2.2 billion) during the latter half of 1965.³³

THE MANNED FACTOR

While various organizations struggled to get the spacecraft through the development phase, human factors experts concentrated on the progress of the spacesuit and the selection of astronauts. For some time, the suit had met turmoil, schedule delays, and technical problems. Early in 1962, Houston had forced a marriage between Hamilton Standard (for a portable life support system) and the International Latex Corporation (for the suit). Hamilton Standard managed the whole system, known as the extravehicular mobility unit. From the beginning, the arrangement proved unworkable.

Just how unworkable was revealed in the spring of 1964, when prototype suits used in the command module mockup review turned out to be incompatible with the Apollo spacecraft cabin. NASA officials had to fall back on Gemini suits for Block I earth-orbital flights. This substitution gave Hamilton Standard and International Latex a chance to straighten

out their problems, but borrowed time did not spell progress. Early in 1965, Hamilton Standard announced that its system manager for the backpack had begun in-house work on backup components for the suit (such as helmets and suit joints). The company had thus become a competitor of its own subcontractor. In February, Hamilton Standard reported that it intended to cancel the International Latex contract, citing poor performance, late deliveries, and cost overruns. Houston concurred.

Houston had also started some remedial actions. In January, David Clark Company, maker of the Gemini suit, had received a contract for backup development of an Apollo Block II suit. After six months, Houston would compare David Clark's suit with what Hamilton Standard, aided by B. F. Goodrich Company, was turning out. International Latex, informed that it was not being considered in the competition, nevertheless asked permission to submit an entry. When Crew Systems Division tested the three suits in June, International Latex had by far the best product.³⁴

In mid-September, Gilruth and Low told Mueller and Phillips that Hamilton Standard would continue to manufacture the backpack. To eliminate the integration problems of the past, Houston would manage the total system and International Latex would develop the suit under a separate contract. This arrangement was agreeable to NASA Headquarters.³⁵

The other major activity in human factors was the expansion of the astronaut corps. During 1962 and 1963, NASA had selected the second and third groups of pilots. These 23, the Gemini generation, with the original seven formed the basic pool for Apollo crews. In 1965, a new breed, called "scientist-astronauts," joined the ranks in training at Houston. NASA Headquarters hoped to mollify some of the scientific grumblers and to strengthen its ties with the scientific community by emphasizing Apollo's potential contribution to science—not only from the instruments that would send back information from the moon but from the men who would fly them there. Surprisingly, some of the drive to enlist these scientist-crewmembers came from engineering-oriented Houston.

Robert B. Voas, human factors assistant to Gilruth and a key figure in setting up procedures for selecting Mercury pilots, had conferred with NASA Director of Space Sciences Homer Newell in Washington in 1963 about Houston's views on scientists for the space program. Voas later met with Eugene M. Shoemaker (of Newell's office), Joseph Shea, and George Low to discuss the most appropriate specialties. With an eye to lunar-surface, long-duration, and earth-orbital activities, the quartet agreed that the disciplines needed were geology, geophysics, medicine, and physiology.

At this September 1963 meeting, Voas emphasized that Houston wanted qualified pilots, but Shea saw no need for any previous flying experience. Why not take this opportunity to introduce methods for selecting and training nonpilots? In the end, the consensus was that candidates with flying

CHARIOTS FOR APOLLO

backgrounds would be given preference but that applications from otherwise qualified men who lacked this training would be accepted. The National Academy of Sciences (NAS) should be asked to help recruit and select scientists for the program. Administrator Webb approved the recommendation.³⁶

Harry H. Hess of NAS agreed in April 1964 to have his Space Science Board define appropriate scientific qualifications (age and physical criteria would be Houston's responsibility). Hess established an ad hoc committee, which submitted its report to Newell in July. In October, NASA announced that it was looking for astronauts with scientific training. For the first time, the selection criteria did not include a requirement for test pilot proficiency. Selectees who were not qualified pilots would be taught to fly after they joined the program. More than 1000 applications had been received by December; 400 of these were forwarded to Hess's board in February 1965 for academic ranking.³⁷

In June, NASA announced that 6 scientist-astronauts had been chosen from 16 nominated by the science board. In the group were one geologist (Harrison H. Schmitt), two physicians (Duane E. Graveline and Joseph P. Kerwin), and three physicists (Owen K. Garriott, Edward G. Gibson, and F. Curtis Michel). Two of the men, Kerwin and Michel, were qualified jet pilots, but the others were not. These four reported to Williams Air Force Base, Arizona, on 29 July for a year of flight training before joining their colleagues in Houston.³⁸

Gilruth wanted another team of pilot-astronauts, and he sent Slayton to Washington to argue the case before Mueller on 15 January 1965. Mueller was cool to the idea, but he later told Gilruth that he might bring another group on board in the fall. On 10 September, NASA announced it would recruit a fifth set of astronauts to ensure "an adequate number of flight crews for Project Apollo and future manned missions."³⁹

PORTENTS FOR OPERATIONS

While Phillips and Shea worked on Apollo spending, schedules, mission assignments, and crew selection, Wernher von Braun and his Marshall Space Flight Center colleagues launched a series of three satellites that calmed many of the fears about micrometeoroid hazards of manned space flight in earth orbit. Astronomers had warned about the dangers of space dust to extended spacecraft flights, but Project Mercury had encountered no insuperable difficulties. With Gemini plans for manned spacecraft spending as much as two weeks in space, however, it was imperative that NASA have data from unmanned missions.

NASA's Office of Advanced Research and Technology and Marshall laid plans for a vehicle called "Pegasus" and hired the Fairchild Stratos

Corporation to build it. By 1964, preliminary designs had been completed and ground testing begun. After considering various shapes, even some resembling parasols, Fairchild adopted a simple flat wing that would deploy in orbital flight to a span of 30 meters and expose 80 times more surface—a total of 700 square meters—than any previous detector in orbit.⁴⁰

The last three Saturn I launches—numbered, in an odd sequence, 9, 8, and 10,* and called Saturn-Apollo (SA) or Apollo-Saturn (AS), depending on which documents (Marshall or Manned Spacecraft Center) were read—carried both Pegasus satellites and boilerplate (BP) Apollo spacecraft. SA-9 (or AS-103) was launched from the Cape on 16 February, tossing its two payloads into separate orbits. During its fourth revolution, the Pegasus registered its first micrometeoroid hit; two weeks later the count reached only a score; and by May the total was not more than 70. When the other Pegasus missions, launched on 23 May and 30 July, encountered as little orbital debris, Apollo engineers were more confident that micrometeoroids would cause few problems in earth orbit to the thin-skinned service module and much less to the command module wrapped in its protective heatshield cocoon.⁴¹

Pegasus provided near-earth data to Apollo; another unmanned vehicle, Ranger, gave a view of the ultimate goal—the moon. After many failures and in July 1964 one resounding success, Ranger ended with two sterling flights, one in February and one in March 1965—much to the relief and credit of the Jet Propulsion Laboratory, the parent organization. *Ranger VIII*, aimed at the moon's equatorial zone in the Sea of Tranquility, transmitted more than 7000 pictures before it crashed. Engineers and scientists had an opportunity to study features no more than 30 centimeters in size. *Ranger IX*, heading for the crater Alphonsus, made the three-day trip with scarcely a course correction. Telemetry from this vehicle, translated and fed through commercial television, gave the public its first close-up view of the moon.⁴²

Manned space flight was a beehive of activities in 1965, with the Gemini program recording five outstanding missions. The Soviet Union had twice flown its multimanned Voskhod spacecraft—in October 1964 and March 1965—and the United States was eager to rejoin the competition. On 23 March after a 22-month hiatus in American manned flight, Virgil Grissom and John Young, in a three-orbit flight aboard *Gemini III*, fired their spacecraft thrusters and changed their orbit. For the first time, man was truly controlling a spacecraft and its direction and speed in space. But this was only a spacecraft qualification flight. More ambitious missions were ahead for Gemini, to test the abilities of the astronauts in space and ground

* SA-9 was the last of the eight S-I first stages built by Marshall; SA-8 was the first built by Chrysler at the Michoud facility in Louisiana. Chrysler needed more time to develop its stage, so SA-9 flew first.

CHARIOTS FOR APOLLO

crews in the control center and around the worldwide tracking network in preparation for Apollo.

The next two Gemini missions, *IV* and *V*, were stepped increases in endurance, four days and eight days, each flight with its individual flavor. James McDivitt and Edward White flew a four-day mission 3–7 June that featured extravehicular activity and a practice rendezvous with the second stage of their launch vehicle. White, using a hand-held jet gun, propelled himself through space and floated at the end of a snakelike eight-meter tether with considerable aplomb.* The attempt to maneuver up to the spent booster stage was not so successful, however, causing some exponents of rendezvous to worry about the future. But little more than two months later, 21–29 August, Gordon Cooper and Charles Conrad embarked on an eight-day voyage and successfully carried out a “phantom rendezvous,” catching an imaginary moving target set up by the flight controllers. Deputy Administrator Hugh Dryden wrote President Lyndon Johnson that the success of *Gemini V*, clearing the way for a two-week endurance test, “has assured us of man’s capability to travel to the moon and return.”⁴³

Although Dryden did not live to see it (he died on 2 December), the year ended with the most exciting and ambitious space flight up to that time. Known to many as the “Spirit of ’76,” the concurrent flight of two manned Gemini spacecraft proved the feasibility of both long-duration flight and rendezvous. It began with the launch of *Gemini VII*, piloted by Frank Borman and James Lovell, on 4 December. Eleven days later, Walter Schirra and Thomas Stafford flew *Gemini VI-A* to a rendezvous with their orbiting compatriots to cap a banner year in space.⁴⁴

Gemini’s successes, although answering important questions, spawned some unwelcome suggestions for Apollo. White’s spectacular extravehicular operation touched off plans for a similar exercise in the first manned Apollo flight; Shea vetoed that idea in a hurry. An even grander scheme pitted Gemini against Apollo. LEO, for “Large Earth Orbit”—all the way around the moon—was championed by Charles Mathews and André Meyer of the Gemini office and subsequently endorsed by Gilruth and Mueller. Since LEO could put Americans in the vicinity of the moon earlier than Apollo, it would be a big leap forward in the space race, which still loomed large in the minds of many people. Four Russian Luna missions had unsuccessfully attempted soft landings during 1965, demonstrating that the Soviet Union was still interested in the lunar target. Seamans vetoed LEO, believing Apollo needed no more competition. But Congress got wind of the plan and started asking questions. When Representative Olin E. Teague wanted to know if there would be any advantages to such a mission, Webb answered that it would be expensive and would still not guarantee success

* Soviet Cosmonaut Aleksey Leonov had taken the world’s first space walk when he left the confines of *Voskhod II* on 18 March 1965.

in beating the Russians to a lunar landing. Apollo was operating on a thin margin of resources as it was; if Congress wanted to spend more money, he told Teague, "I believe it would be in the national interest to [give it to] the Apollo program."⁴⁵

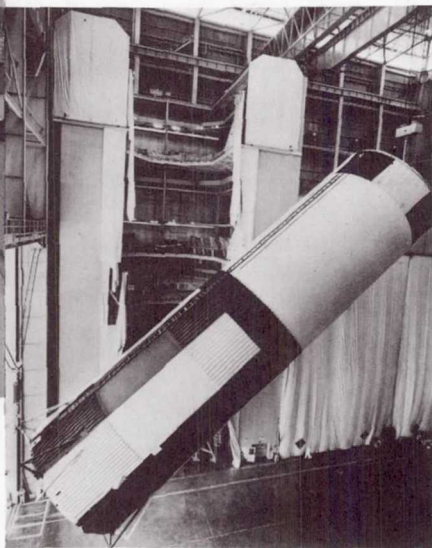
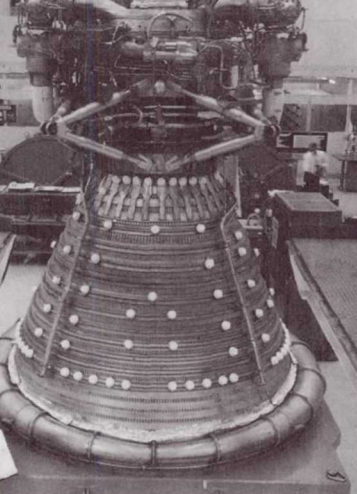
So Gemini and Apollo were not to be rivals. Then could they perhaps assist each other? Howard W. Tindall, Jr. (whose specialty was mission planning and whose "Tindallgrams" achieved local fame), did not think so.* They shared the mutual objectives of rendezvous, docking, and long-duration flight, but hardware and mission planning were so different and the respective managers were so busy trying to meet schedules that they could seldom afford the luxury of keeping abreast of each other's program.⁴⁶

Apollo also had some operational successes in 1965—none as spectacular as the Gemini flights but one at least more breathtaking than expected. Several dozen newsmen gathered at White Sands Missile Range, New Mexico, on 19 May to watch Mission A-003, an abort test of a boilerplate spacecraft at an altitude of 35 000 meters. At 6 that morning, the Little Joe II ignited and rammed its payload skyward. A few seconds after liftoff, a fin-vane at the base of the booster stuck and started the 13-meter-tall spacecraft-booster combination spinning like a bullet. Twenty-six seconds into the flight and still on a true course, the vehicle started coming apart. The abort-sensing system signaled the launch escape tower rocket to fire and pull the spacecraft away at an altitude of 4000 meters. While newsmen watched the fluttering remains of the Little Joe II, BP-22's parachutes lowered it gently to the desert floor. Apollo had another answer: the launch escape system worked in a real abort situation.⁴⁷

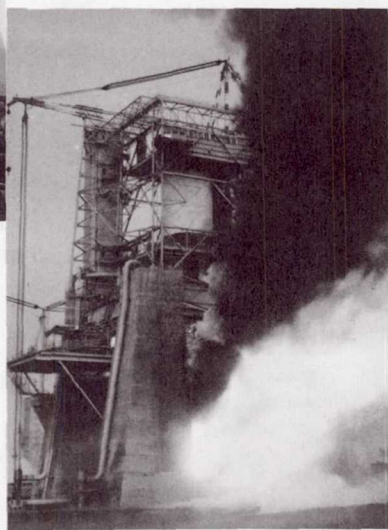
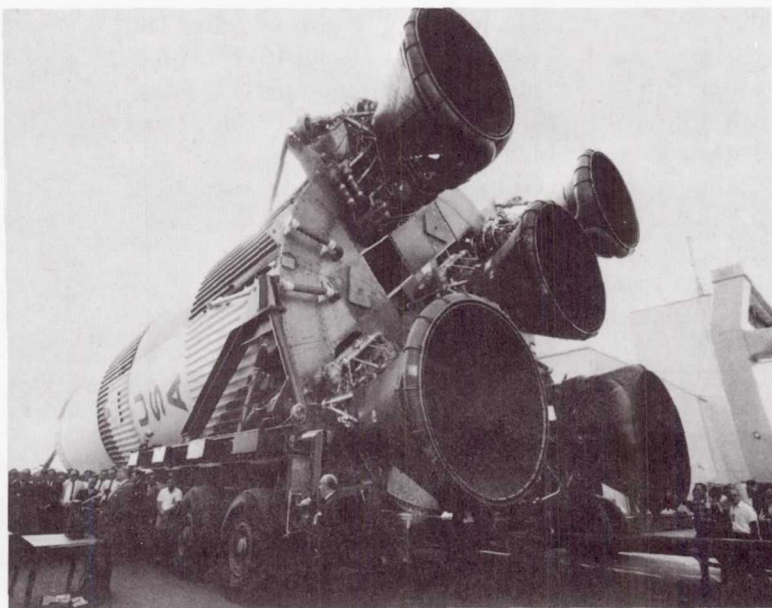
Little more than a month later, on 29 June, the launch team in New Mexico prepared to test an abort off the pad. The year before, a similar test had proved the escape tower rocket could jerk the spacecraft safely away from an exploding launch vehicle. But both the spacecraft and its escape system had since gained weight. In the second test, the rocket pulled the spacecraft higher in the air and farther downrange than expected.⁴⁸

Perhaps one of the more heartening events during 1965 was the static-firing at the Mississippi Test Facility of the S-IC, the first stage of the Saturn V. The five F-1 engines, burning for six and a half seconds, produced the designed 33.4 million newtons (7.5 million pounds) of thrust, as much power as five Saturn Is lashed together. Going on up the Saturn

* Some Apollo engineers did not agree with Tindall. James C. Church thought Apollo might learn something about program control from Gemini, and Calvin H. Perrine wanted some expert advice on ground test programs from the office that had just gone through that experience. Duncan believed the Gemini sextant might be modified for use on Apollo. Rolf W. Lanzkron and Joseph P. Loftus, Jr., were anxious to learn anything they could from the crews that they might apply to Apollo. And H. B. Graham of North American, who made a comparison of Apollo and Gemini checkout procedures, assumed that further study might show some of the Gemini measures applicable to Apollo.



The F-1 engine at upper left, one of five fitted into the Saturn V's S-IC first stage, being prepared at the Rocketdyne plant in California for shipment to the Michoud launch vehicle assembly plant in Louisiana. At upper right an S-IC stage at Michoud, 27 June 1965, is removed from its vertical assembly tower. After installation of wiring and components, this ground test version—the first in the Saturn V development program—would be shipped by barge to Marshall Flight Center in Alabama. Marshall Director Wernher von Braun (at the microphone in the center photo) held a brief ceremony 26 September 1965, accepting the first flight S-IC. Below, S-IC-T is fired for 2½ minutes at Marshall in an August 1965 ground test.



V stack, the S-II second stage was static-fired in April and the S-IVB third stage in August, with excellent results.⁴⁹ Although the Saturn I, with its ten straight launch successes, had already proved the clustered-stage concept, Mueller and his staff breathed easier after the Saturn V tests.

Only solar radiation remained a worry of first rank at the end of 1965. During the year, a Solar Particle Alert Network was set up to study sunspots and to develop some techniques for predicting solar storms, so Apollo crews could take protective action against dangerous doses of radiation. The cyclical nature of sunspot behavior was, fortunately, fairly well understood. By using existing observatories and adding a few more (one at Houston), NASA intended to plan Apollo missions to avoid the periods of greatest solar activity.⁵⁰

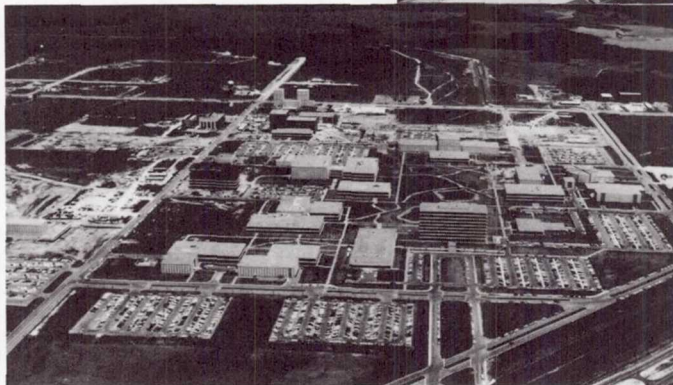
A new hazard discussed with increasing frequency during the year was the danger of back contamination from pathogenic organisms aboard a returning lunar spacecraft. The possibility of contaminating other planets during space exploration had long been recognized; now the risks of returning materials to the earth after exploratory voyages had to be faced. The United States Public Health Service was brought in to advise NASA on care of lunar samples and crews. Sharing the apprehensions, Congress hastily authorized the construction of a special quarantine facility in Houston. The Lunar Sample Receiving Laboratory, hurriedly built during the next two years, was one of the most elaborately safeguarded biological facilities in the world.⁵¹

Another indication that the operational phase of Apollo was approaching was Mueller's creation in July of a Site Selection Board to recommend lunar landing areas. Gilruth sent William Lee and William E. Stoney, Jr., to serve on this board, as well as on the Ad Hoc Surveyor/Lunar Orbiter Utilization Committee (which Gilruth believed belonged in the same basket, anyway). The next month, John E. Dornbach's Lunar Surface Technology Branch compiled lists of candidate sites. In October, NASA announced that ten areas had been selected and that they would be photographed by Lunar Orbiter cameras during 1966.⁵²

Picking sites and building a facility to handle samples and crews on their return to earth were good starts toward operations, but some communications and control systems problems remained to be ironed out. Early in its planning, NASA had seen the need for a "real-time computer complex" (RTCC) for instantaneous information on and control of manned space missions. Located at Goddard during all of Mercury and the early part of Gemini, the complex linked 17 ground stations around the globe and permitted observers to monitor manned flights on virtually a continuous basis. In addition, Mercury, Gemini, and Apollo needed digital applications in six other areas: premission planning and analysis; space flight simulations to aid manufacturers and astronauts; launch operations, so data could be instantly checked and analyzed; physiological monitoring of crewmen in



Mission Control Center, Houston, above. At right, the mission operations control room during the Gemini V flight in August 1965. The room is in the windowless part of the building. Below, Manned Spacecraft Center during the mission. Mission Control is at the center, just to the right of the multistory building under construction.



flight, using biosensors; postflight mission analyses, so data on each flight could be catalogued and filed for future reference; and in the arena of worldwide testing, known to NASA by the fishy-sounding acronym CAD-FISS, for computer and data-flow integrated subsystems.

After lengthy technical and administrative arguments, NASA moved the computer complex to Houston to form an "integrated mission control center." The center would have four main duties: processing global signals for display to flight controllers, computing and sending antenna-aiming directions to the global tracking stations, providing navigation information to the spacecraft, and simulating all mission data for personnel training and equipment checkout. By spring of 1965, Houston's computer complex was nearly ready, with five IBM 7094 model II computers on the line. Flight Director Chris Kraft assured Mueller the complex would be ready to control *Gemini IV* in June, and he was right. In September, a supplemental Univac 1230 was added to the complex, and plans were laid to replace the 7094s with new IBM 360 model 75s. Although the 7094s remained in service

until 1968, modifications and upgrading provided a daily capacity of 80 billion calculations.⁵³

Besides the enormous ground-based complexes, American industry had developed small computers for aeronautics and astronautics. While MIT's Instrumentation Laboratory was developing the Apollo guidance and navigation system, a major part of which was the onboard computer, throughout the computer industry there were breakthroughs in technology, based on microminiaturization, transistors, integrated circuits, thin-film memories, high-frequency power conversion, and multilayer interconnection boards.

Mercury had flown without onboard computers, but Gemini needed a digital computer and visual displays to control ascent, rendezvous, orbital navigation, and reentry. IBM delivered the first computer for a Gemini spacecraft in 1963, but NASA had been shopping around for a computer source for Apollo even earlier. In May 1962, NASA and MIT had selected Raytheon. Drawing on MIT's experience with Polaris missiles and nuclear submarines, Raytheon produced a general-purpose prototype by mid-1965.

The first Block I computer embodied significant advances over other computers. But it was soon discontinued because NASA decided to delete inflight maintenance and because the design was not satisfactory in either malfunction detection or packaging. The next, or Block II, version corrected these weaknesses. Weighing 31 kilograms and consuming only 70 watts of power during normal operation, the Block II "brains" incorporated redundant systems and had the largest memory of any onboard spacecraft computer to that time (37 000 words).⁵⁴

THE COURSE AND THE FUTURE

Two major questions faced NASA planners during 1965. Was Apollo on course, at what was essentially its midpoint, to meet the goal of a lunar landing before the end of the decade? And what should follow Apollo in the manned space flight arena?

To find the answer to the first question, the House Subcommittee on NASA Oversight, led by Teague, set up a special staff in June to assess schedules, funding, and spacecraft management. After three months of probing, a staff study published under the title *Pacing Systems of the Apollo Program* identified seven bottlenecks in Apollo. For the lander, pacing systems were the descent engine, rendezvous radar, weight growth, and ground support equipment; for the command and service modules, they were engineering drawing releases, subassembly delivery and certification, and tooling and fabrication of the heatshield. The subcommittee concluded that NASA was applying its resources effectively to these problems and the program was progressing on schedule.⁵⁵

NASA leaders, meanwhile, were worrying about what would come after

CHARIOTS FOR APOLLO

Apollo, in view of the rising demand for dollars for human resources on the domestic front and military commitments abroad, particularly in South-east Asia. Out of this concern came a new Headquarters program office called Apollo Applications (AAP), headed by David M. Jones, an Air Force major general assigned to NASA. Mueller had two objectives in setting up this office: preserving the Apollo team and using the hardware to get some pay-offs in science and earth resources.

To Houston this was evading the issue. In a lengthy letter to Mueller, MSC Director Gilruth manifested "deep concern that . . . a critical mismatch exists between the present AAP planning, the significant opportunities for manned space flight, and the resources available for this program." Speaking both for himself and his deputy, George Low—who as much as anyone within NASA had helped chart the course for Apollo—Gilruth proposed that "the next major step in manned space flight should involve a large permanent manned orbital station," which would be "an operational step leading to man's exploration of the planets." As structured, he said, AAP would simply maintain the status quo in the production and flight of Saturn-Apollo hardware. "Merely doing this, without planning for a new program, and without doing significant research and development as part of AAP, will not maintain the momentum we have achieved."⁵⁶

Thus the total climate of opinion surrounding Apollo had altered. No longer did the moon seem the all-important—and all-consuming—goal it had been. Other objectives in the new ocean of space were taking shape. But conditions were not ripe: 1966 would be a year of progress for existing manned space flight programs, not a curtain-raiser for any major new projects. In one more flight, Little Joe II would complete its series of Apollo tests; after five more missions, which made orbital flight routine, Gemini would phase out and Lunar Orbiter and Surveyor would phase in; and Saturn and Apollo vehicles would taste the first fruits of success.

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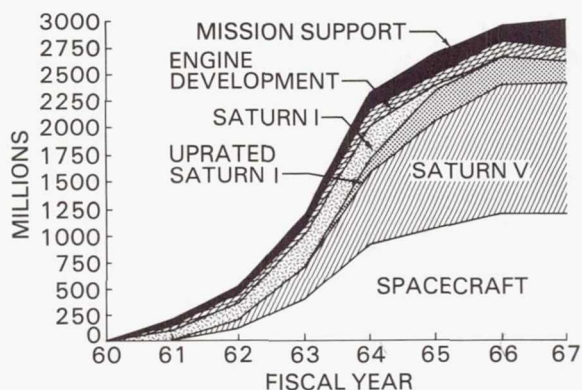
Moving toward Operations

1966

By 1966 Apollo had lost much of the emotional support of Congress and the public that had welled up five years earlier in the wake of the Soviet Vostoks. The drop was reasonable, since the successes of the Gemini and Saturn I programs had led many Americans to believe the space race with Russia had been won. Moreover, domestic and foreign commitments, made primarily in 1965, to President Johnson's "Great Society" and to Southeast Asia had placed more demands on tax dollars than had been foreseen. For fiscal 1967, NASA submitted a budget request of \$5.58 billion, the President cut it to \$5.012, and Congress chopped it to \$4.968. Apollo came through virtually unscathed; but its follow-on, Apollo Applications, felt the weight of the Budget Bureau's ax.¹

Obtaining funds for space exploration might be becoming more difficult, but most NASA officials had no time to worry about future programs. Apollo boilerplate flight tests had ended, and production spacecraft would soon fly atop the Saturn IB. Manned Spacecraft Center Director Robert Gilruth told Chris Kraft, Director for Flight Operations in Houston, to get his people started on the job ahead.

By January 1966, Kraft's group had drafted a preliminary "operations plan." In February it distributed a more complete version that pinpointed the responsibilities and functions of everyone connected with flights, beginning with Director Gilruth. The plan listed 19 specific documents, ranging from the "mission directive" prepared by Joseph Shea's Apollo office to the "postflight trajectory analysis" compiled by Kraft's own direc-



Apollo program funding through fiscal 1967, on a 1966 chart. "Up-rated Saturn I," a name that did not stick, is the Saturn IB launch vehicle.

torate, that would be essential in conducting a mission. Kraft also named John Hodge as flight director for AS-202 and AS-203. Kraft, himself, would direct AS-204, the first manned mission in the program.*²

QUALIFYING MISSIONS

Before starting Apollo-Saturn IB launches, however, the operations people had to clean up one outstanding matter in New Mexico. NASA had hoped to finish the Little Joe II abort qualification program by the end of 1965, but on 17 December the Flight Readiness Board refused to accept the booster and canceled a launch set for the next day. A month later, at 8:15 on the morning of 20 January 1966, the last Little Joe II headed toward an altitude of 24 kilometers and a downrange distance of 14 kilometers. Then, as designed, the launch vehicle started to tumble; the launch escape system sensed trouble and fired its abort rocket, carrying the command module away from impending disaster. All went well on Mission A-004—the launch, the test conditions, the telemetry, the spacecraft (Block I production model 002), and the postflight analysis. The spacecraft windows picked up too much soot from the tower jettison motor, but the structure remained intact. Little Joe II was honorably retired, its basic purpose—making sure the launch escape and earth landing systems could protect the astronauts in either emergency or normal operations—accomplished.³

After the last Little Joe flight, the scene shifted to Florida, where a Saturn IB, the first of the uprated vehicles† slated to boost manned flights into earth orbit, was ready. AS-201 did not get a lot of publicity, but Dale Myers and his North American crew considered its spacecraft CSM-009 their "teething" operation:

* Glynn S. Lunney had already been assigned to direct AS-201, scheduled to fly 26 February 1966.

† The Saturn IB first stage differed from that of the Saturn I in that its eight engines had been uprated from 5.8 million to a total of 7.1 million newtons (from 1.3 million to 1.6 million pounds of thrust).

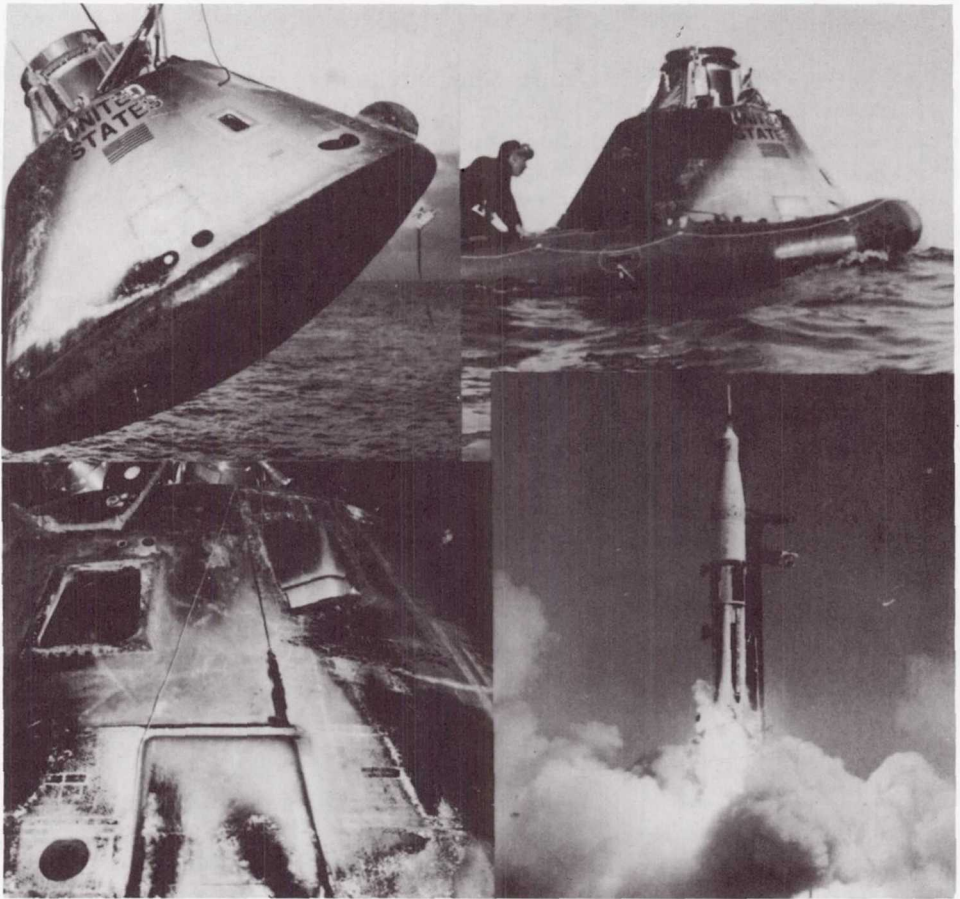
MOVING TOWARD OPERATIONS

It . . . proved out our procedures, our checkout techniques, and proved that this equipment [fitted] together. . . . And we got lined up so we [were] able to handle operations both at the Cape and [in Downey]. Although spacecraft 009 had some problems in flight . . . we got what we were looking for from the primary objective, . . . real good data on our heatshield, which we just can't get any testing on in any other way.⁴

The Saturn IB first stage, assembled by Chrysler and with its eight H-1 engines built by Rocketdyne, had been erected on Complex 34 at Cape Kennedy in August 1965. Command and service module 009 was hoisted atop the booster on 26 December. Between those dates, the new S-IVB stage built by Douglas, with its single Rocketdyne J-2 engine, had been mated to the first stage, checked out, and fitted with an 1800-kilogram "instrument unit," or guidance ring, made by IBM Federal Systems Division. The top third of the stack—the spacecraft—launch vehicle adapter, the cylindrical service module, the conical command module, and the pylon-shaped launch escape tower—had been North American's responsibility. Once they were stacked together, NASA assumed control. It took two pages to list AS-201's test objectives, but NASA's main aims were to check the compatibility and structural integrity of the spacecraft and launch vehicle and to evaluate the spacecraft's heatshield performance as the vehicle plunged through the atmosphere.⁵

Spacecraft 009 assembly began in October 1963 and continued throughout 1964, with the inner-shell aluminum-honeycomb pressure vessel taking shape concurrently with the stainless-steel-honeycomb outer shell and its ablative heatshield. By April 1965, 009 had reached the test division at Downey, where it spent the summer. After a review at the factory on 20 October, NASA's Apollo engineers approved the spacecraft for shipment to Cape Kennedy. Three months of servicing and checkout followed before AS-201 was ready for its voyage.

On 20 February 1966, launch technicians at the Cape began a three-day countdown, fully expecting some of the spacecraft's systems to delay the launch. But weather turned out to be the chief problem, causing two postponements. At 5:15 on the afternoon of the 25th, the countdown resumed. Three seconds before ignition—at 9:00 the next morning—a computer signaled that pressure in two helium spheres on the Saturn IB was below the danger line. The count was recycled to 15 minutes before launch and stopped. Discussions waxed hot between Huntsville and Cape engineers. Since no one could be sure how serious the problem really was, the mission was scrubbed at 10:45. Deciding that the drop in pressure was probably caused by either an excessive flow of oxygen in the checkout equipment or leakage in the flight system, Wernher von Braun's Saturn team recommended advancing the ground pressure regulator to maintain a higher pres-



Apollo-Saturn 201 mission, 26 February 1966: launch, recovery (swimmers have attached a flotation collar, a device used in the Gemini and Mercury programs), and two views of the heatshield.

sure in the spheres. Kurt Debus' Cape crew agreed, and the launch was back on the track by 10:57.⁶

At 11:12 a.m. 26 February, AS-201's first stage ignited and drove the combined vehicles up to 57 kilometers where, after separation, the S-IVB took over, propelling the payload up to 425 kilometers. The second stage then dropped off, and the spacecraft coasted in an arc, reaching a peak altitude of 488 kilometers. At the zenith, the service module engine fired for 184 seconds, hurtling the command module into a steep descent. After a 10-second cutoff, the rocket engine fired again, for 10 seconds, to prove it could restart. The two modules then separated. The command module, traveling at 8300 meters per second, turned blunt end forward to meet the friction caused by the growing density of the atmosphere.⁷

Both booster and spacecraft performed adequately. From liftoff in

MOVING TOWARD OPERATIONS

Florida to touchdown in the South Atlantic, the mission lasted only 37 minutes. The spacecraft was recovered by the U.S.S. *Boxer* two and a half hours after splashdown. AS-201 proved that the spacecraft was structurally sound and, most important, that the heatshield could survive an atmospheric reentry.

There were several malfunctions, mostly minor. Three were serious. First, after the service propulsion system fired, it operated correctly for only 80 seconds. Then the pressure fell 30 percent because of helium ingestion into the oxidizer chamber. Second, a fault in the electrical power system caused a loss of steering control, resulting in a rolling reentry. And, third, flight measurements during reentry were distorted because of a short circuit. Although Mueller agreed that the mission objectives had been met, these three problems would have to be corrected.⁸

The service module engine received instant attention. North American's Robert E. Field and Aerojet-General's Dan David (the engine's Apollo manager) ordered an analysis of what had gone wrong. The engine had operated well enough to finish the mission, but Field and David had to be sure that the Block II engine (undergoing ground testing) would not run into a similar situation during a lunar mission. They learned that a leak in an oxidizer line had permitted helium to mix with the oxidizer, causing the drop in temperature and pressure.

For all of Houston's insistence on redundancy, this was one major system that had no backup. And it was a vital system. Because of the lunar-orbit rendezvous decision, it had a variety of jobs: midcourse corrections on the way to the moon, lunar-orbit insertion, and transearth injection (placing the spacecraft on the homeward path) on the return voyage. Weight penalties forbade a second propulsion system; the service module engine had to carry its own built-in reliability.⁹

To allow time for studying and solving propulsion system problems and to prevent program delays, NASA managers shuffled the launch sequence. Since AS-203 was not scheduled to carry a payload, it would be flown before AS-202. Billed as a launch vehicle development flight, the third Saturn IB was to place its S-IVB stage in orbit for study of liquid-hydrogen behavior in a weightless environment.* On 5 July 1966, AS-203 was launched from Kennedy to insert the 26 500-kilogram second stage into orbit. Ground observers monitored the S-IVB by television during its first four circuits, watching the 8600 kilograms of liquid hydrogen remaining in its

* Langley Research Center made another study of liquid-hydrogen behavior under zero gravity during 1966. On 7 June, Wallops Island crews launched a two-stage Wasp (Weightless Analysis Sounding Probe), carrying a 680-kilogram scale model of an S-II fuel tank. For seven minutes of weightless flight, television cameras mounted on a transparent tank transmitted data back to Wallops that added to the confidence of Houston engineers in launching AS-203 the following month.

CHARIOTS FOR APOLLO

tanks. Despite some turbulence, the S-IVB appeared capable of boosting the astronauts on a flight path to the moon.¹⁰

Mission AS-202 was twice as complicated as AS-201. It would last 90 minutes, reach an altitude of 100 kilometers, and travel two-thirds of the way around the world. Launched on 25 August, AS-202 had a host of objectives, but the focal interest was service module engine firings. With clockwork precision, the motor fired four times, for a total operating time of 200 seconds. After a steeper reentry than expected, the command module was plucked from the Pacific Ocean near Wake Island by the recovery forces ten hours after liftoff and placed aboard the U.S.S. *Hornet*. On the carrier, specialists found that the heatshield and capsule had come through reentry admirably.¹¹

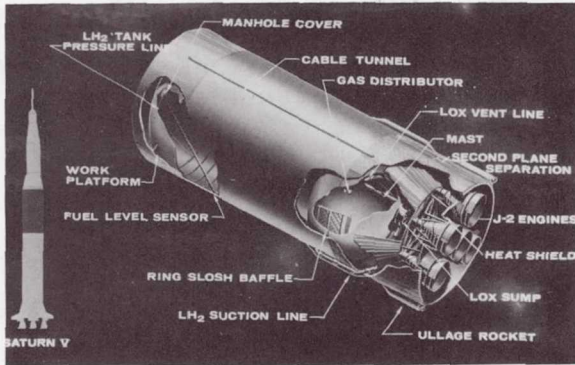
TROUBLES AND TROUBLESHOOTERS

Saturn IB flights, for the most part, ran smoothly in 1966. Unfortunately, this was not true for all of Apollo. Early in the year, NASA Apollo Program Director Samuel Phillips and a cadre of analysts completed a survey of vehicles and management at North American, after several months of probing into activities at Downey, Seal Beach, and El Segundo. Phillips' group noted that organizational and personnel weaknesses were hampering the contractor's attempts to meet command and service module schedules, but the biggest problem was the S-II second stage of the launch vehicle, which threatened to block the chances of flying an all-up vehicle on the first Saturn V launch.

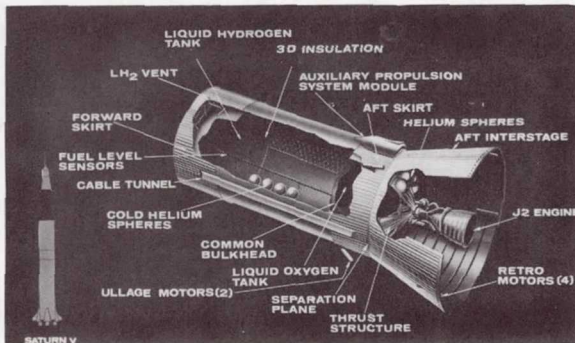
Despite two successful ground tests, on 29 December 1965 and 12 January 1966, the S-II was behind schedule and in trouble. North American realized this and hired a new manager, Robert E. Greer, a retired Air Force general, to get S-II development back on the track. By spring, Greer and his troops had gone to the Mississippi Test Facility, near the Pearl River north of New Orleans, to begin an intensive ground test program. For 15 seconds on 23 April, the five J-2 liquid-oxygen and liquid-hydrogen engines roared into action, producing the designed thrust of 4.5 million newtons (one million pounds).¹²

Three more firings were attempted—on 10, 11, and 16 May—but the engines were cut off too soon by faulty instrumentation. In two more tests, on the 17th and 20th, the engines fired for 150 and 350 seconds. The next scheduled 350-second test, on 25 May, met problems when fire broke out in two places on the S-II. Three days later, while the stage was being removed from the stand, a liquid-hydrogen tank exploded, injuring five persons and damaging the test stand.¹³

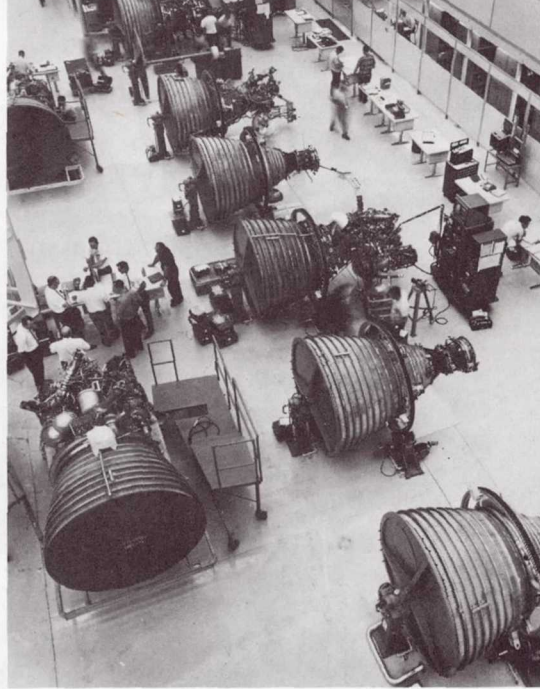
Although it was a gloomy day in Mississippi, 25 May 1966 was still a milestone for Saturn V. Two states away, in Florida, NASA ceremoniously



Saturn's S-II stage



Saturn S-IVB stage



J-2 engines at the Rocketdyne plant in California. Five of these engines, propelled by liquid oxygen and liquid hydrogen, were used in the Saturn V's S-II second stage, and one was used in its S-IVB third stage (the S-IVB was also the second stage of the Saturn IB).

rolled out its 2700-metric-ton, diesel-powered, steel-link-tread crawler-transporter loaded with the 111-meter-tall, 196 000-kilogram* Apollo-Saturn vehicle. Just before this impressive mass began moving at a snail's pace away from the Vehicle Assembly Building, NASA Deputy Administrator Robert Seamans said: "I for one questioned whether a vehicle the size of Apollo/Saturn could get out to the pad . . . or not." It could.¹⁴

However well the rollout augured for Apollo's eventual success, right then the S-II stage was in trouble. NASA Manned Space Flight Director George Mueller began sending weekly assessments of S-II progress to J. Leland Atwood, warning the president of North American that the S-II stood a good chance of replacing the lunar module as the pacing item in Apollo. But Atwood already knew it. That was why he had hired Greer—to bring the S-II more attention at a higher level of management.¹⁵

Mueller also told Atwood that Phillips, on his return from the West Coast, had pointed out problems with the spacecraft. Both earth-orbital (Block I) and lunar-orbital (Block II) versions of the command module

* Dry weight—fully loaded with fuel and oxidizer, it weighed 2 766 000 kilograms.

CHARIOTS FOR APOLLO

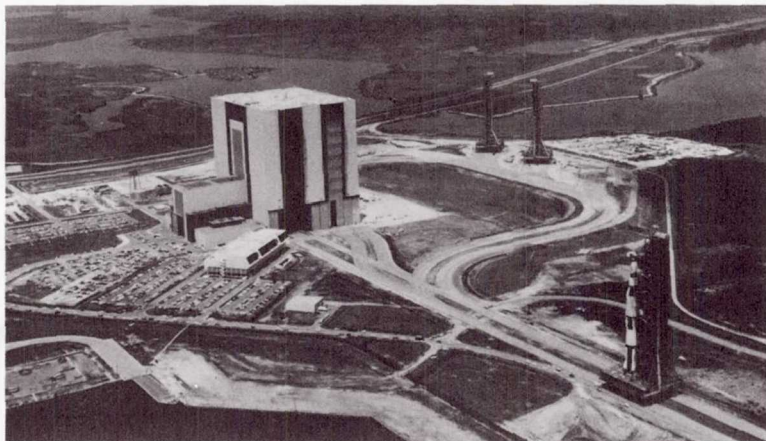
were being plagued during manufacturing by late hardware deliveries from subcontractors and vendors. The most troublesome had been the environmental control unit being developed by AiResearch. Phillips had chided the subcontractor by letter for its poor performance. In October Atwood admitted to Mueller that this system was the most serious threat to meeting spacecraft schedules for the first manned Apollo flight.¹⁶

Phillips' troubleshooting set a pattern for Apollo in 1966; many managers and subsystem managers found themselves dealing, often full-time, with the difficulties in getting qualified vehicles to the launch pad. One of the Houston managers who spent a lot of time trying to straighten out some subsystem that was in trouble was Rolf W. Lanzkron. Phillips had asked Shea to send Lanzkron to General Electric in late 1965 to help get the manufacturer of the ground checkout equipment onto the right path. While Lanzkron was there, GE's general manager for the program, Roy H. Beaton, commented in a letter to Phillips:

As you might well guess he beat the living h— out of us, . . . spurring us on to more effective utilization of our previously mammoth efforts. Despite the bruises, we feel that we are a far more effective organization now as a result of his leadership.¹⁷

And Lanzkron traveled elsewhere. On one occasion he went to Phoenix, where the Sperry Company was having a hard time with the guidance and navigation gyroscopes. For several years, Sperry had been using a commercial detergent, one that many housewives use for washing dishes, to remove grease from the gyro's bearings. Suddenly something went wrong—the grease was not coming off. Baffled at first, Lanzkron and Sperry's own troubleshooters finally discovered that Procter and Gamble had changed its product to include an additive that was supposed to make it better for dishwashing.

The first Saturn V rollout, from the VAB, 25 May 1966.



MOVING TOWARD OPERATIONS

It may have helped the housewife, but the "improved" product certainly hindered the cleaning of the bearings.¹⁸ Solving the gyro problem was a minor achievement in getting systems ready for flight. Over in the state of New York, however, more complex technical, financial, and managerial problems would demand the attention of many, many troubleshooters.

LUNAR MODULE

By 1966, the lunar module had achieved some degree of maturity. Grumman had brought the lander out of the design phase and was trying to move it in the production line. But there were indications that the contractor was going to have problems. Control of in-house costs was fairly efficient; the company's chief difficulties lay in overruns by its subcontractors. R. Wayne Young, MSC's lunar module project officer, estimated that by the end of June Grumman would spend \$24 million more than its allotted funds. Moreover, since late 1965 Grumman's scheduling position had been shaky, with delays indicated virtually across the board.¹⁹

In light of these severe overruns, Houston sent representatives to Bethpage to discuss cost-reduction measures. This conference produced a list of items to either be reduced or chopped from the major subcontractors. Meetings were then held with project manager at each of the subcontractor plants to ram through cutbacks in requirements and manpower. The reviews, lasting a month and a half, culminated in tightened test procedures and performance requirements. To make sure that cost-reduction measures were enforced, Grumman switched from quarterly to monthly meetings with its subcontractors, inviting the appropriate Houston subsystem manager to attend.²⁰

Despite these actions, lunar module costs had not leveled off by late spring. In-house cost control and forecasting had also begun to deteriorate, aggravating the problems already encountered. Against this backdrop, Gilruth met with Grumman's new president, Llewellyn J. Evans, to discuss cost control and management of subcontractors. At Evans' request, Gilruth sent a management analysis group to diagnose and recommend ways to remedy the company's weaknesses. The NASA Management Review Team, headed by Wesley L. Hjernevik of Houston, was composed of members from both Houston and Washington.²¹

Hjernevik's team assembled at Bethpage in June. After a ten-day review, the team reported its findings to company corporate officers and NASA officials. Looking upon the Hjernevik team as a "personal management analysis staff," Evans promptly carried out most of its recommendations on program management, costs, subcontractor control, and ground support equipment. To make sure all orders were followed and all decisions were relayed speedily to operating organizations, Grumman installed Hugh Mc-

CHARIOTS FOR APOLLO

Cullough at the head of a Program Control Office. George F. Titterton moved from his vice-presidential suite to the factory building that housed most of the spacecraft's managerial and engineering staff, thus ensuring a high degree of corporate-level supervision.²²

To bring about the kind of cost forecasting and control that NASA wanted, Grumman adopted "work packages"—breaking the program down into manageable segments, with strict cost budgets, and assigning managers to ride herd on each package. By linking tasks to manpower, program managers could better judge and control work in progress. This approach was a real departure from the commodity-oriented approach used by Grumman until that time. Shea watched these operations closely and on 19 September expressed his belief to Evans that the work packages could control costs and might even effect some modest reductions. In the next two months, however, costs still exceeded budgets in some areas. Unless discipline were enforced, Shea warned Titterton on 18 November, the work packages could turn into so many worthless scraps of paper rather than effective management tools.²³

Hjornevik's team also discovered that no one person had been assigned responsibility for overall subcontract supervision. As a result, this whole area suffered from splintered authority. Grumman appointed Brian Evans to the newly created position of Subcontract Manager, reporting directly to Program Director Joseph G. Gavin, Jr. Evans then assembled a staff of project managers and assigned each to a major subcontract, with jurisdiction over costs, schedules, and technical performance. The strengthened structure was a welcome tonic; hardware deliveries improved and subsystem qualification moved ahead. Titterton also instituted quarterly meetings with presidents of the major subcontractor firms, similar to those held by Mueller for NASA's prime Apollo contractors.²⁴

The weaknesses in ground checkout equipment, which had been a millstone around the contractor's neck since the early days of the program, had developed because Grumman leaders simply had not recognized the immensity of the task. In February 1966 Phillips had pointed out to Shea that this equipment had paced the start of propulsion system testing at White Sands, had hampered in-house activity at Bethpage, and threatened to delay operational readiness of checkout and launch facilities at Kennedy Space Center.* Shea replied that Grumman had put checkout equipment

* After attending a lunar module status review at Bethpage on 18 May, Harold G. Russell, Special Assistant to Phillips for Operational Readiness, expressed his mounting concern about Grumman's chances for meeting the operational readiness dates for facilities at the Cape. The company was reporting delays of two and a half months in support of LM-1, but, Russell told Phillips, "from an analysis of the GAEC internal reporting system (if they really have such a system), the slippages may be worse than they are reporting. I seriously question the GAEC management visibility into their critical problem areas."

MOVING TOWARD OPERATIONS

engineering and manufacturing on a 56-hour work week and was adding manpower to do the job.²⁵

Despite Shea's reassurances and Grumman's attempts at remedial actions, the system failed to improve measurably. Grumman had made progress in engineering design, which was about 80 percent complete; the bottleneck was in fabrication. Phillips and Mueller became thoroughly alarmed. They suggested that Grumman purchase components for the system from General Electric and other vendors who were having more success in the field. Subsequently, Grumman did put a variety of ground support items up for competitive bid.²⁶

At Bethpage, the Hjernevik team's difficulty in assessing the ground support equipment problem hinged on the fact that Grumman did not have a coordinated plan. The team suggested that Grumman devote more attention to specific areas such as deadlines for drawing releases, an intensified production effort, and a daily status review by program management. Llewellyn Evans named John Coursen to oversee ground-support-equipment manufacturing and set aside a separate building for the fabrication workers, whose numbers had grown considerably. Procurement was also strengthened, with Robert Brader heading a staff of a dozen purchasing people. And, finally, a "GSE command post" was established to track day-by-day progress.²⁷

Actions at Bethpage were complemented by moves in Houston. In mid-July, Wayne Young appointed a team to meet with Grumman every month to assess status and tackle problems. At the end of the summer, with the last Gemini flight mission scheduled before the end of the year, Charles Mathews and William Lee shipped some surplus Gemini checkout items to Bethpage.²⁸ Collectively, these measures brought a dramatic turnaround in Grumman's checkout equipment progress. As Gavin later observed: "The tide was turned in midsummer. We were effectively on schedule in mid-October."²⁹

Successfully overhauling management practices and fighting rising costs were commendable accomplishments, but the lunar module faced problems in other areas that were equally dangerous to Apollo. Downey and the command module had been the big technical worry during 1965, Shea said at a meeting in San Augustine, Texas. The lander, which had begun the program a year late, must not be allowed to stumble into the same pitfalls. Echoing Shea's sentiments, William Lee commented that Apollo would be in deep trouble if the lunar module followed the pattern of Gemini and the command module.³⁰

A significant hurdle vaulted about mid-1966 was the final solution of the long-overdue radar-optical-tracker question, the last of the lander's subsystems to be settled. Engineers in the Manned Spacecraft Center's Apollo office and in Robert E. Duncan's Guidance and Control Division had promoted an "olympics"—a contest that pitted the radar against the tracker—and performance trials took place in the spring of 1966. After tests and presenta-

CHARIOTS FOR APOLLO

tions by competing contractors RCA and Hughes Aircraft Company, a review board chose the RCA radar. Although both systems could be developed within the same time and cost (\$14 million), the radar had more operational flexibility than the less versatile tracker. The radar was heavier, but the weight had little influence on the choice, because of Grumman's weight-reduction program of the previous year.

Perhaps the decisive factor in the selection was the outspoken preference of the astronauts. When asked by Duncan to support the olympics, Donald Slayton stated forthrightly: "The question is not which system can be manufactured, packaged, and qualified as flight hardware at the earliest date; it is which design is most operationally suited to accomplishing the lunar mission." In light of recent experience, Slayton and Russell L. Schweickart, the astronauts' representative on the evaluation board, believed that mission planning should make maximum use of Gemini rendezvous procedures and orbital techniques. This should include, they said, "an independent, onboard source of range/range rate information . . . with accuracy on the order of that provided by the existing LEM rendezvous radar." So Grumman, which had slowed down radar development, shifted RCA back into high gear.³¹

The lunar module engines, too, were still having technical troubles, troubles that seemed to defy solution, although none of them were grave enough to threaten eventual success. For the descent engine, these included rough burning; excessive eroding of the combustion chamber throat; burning of the throttle mechanism pintle tip, where fuel and oxidizer met and combustion began; and difficulty in getting presumably identical engines to operate alike.

Design engineers at the Thompson-Ramo-Wooldridge (TRW) Systems Group* made several changes in the pintle tip, the most significant being a switch to columbium to improve thermal characteristics. Other revisions included removing a turbulence ring around the interior of the chamber and realigning the flow pattern of the fuel that cooled the sides of the chamber wall. Although qualification testing was delayed six months, the problems seemed to be solved.³²

Ascent engine technical problems were more fundamental. Bell was plagued by fabrication and welding difficulties and by severe gouging in the ablative lining of the thrust chamber. The injector, which had been fitted with baffles to combat combustion instability encountered during the shaped-charge bomb testing, was also a culprit. After an engineering review and resulting design revisions, including strengthening of the weld areas, Houston suggested that Bell begin work on a backup model. That would be expensive, but something had to be done. Subsequently, an improved injector

* In 1966, TRW's Space Technology Laboratories (the familiar "STL") was renamed TRW Systems Group.

MOVING TOWARD OPERATIONS

demonstrated better burning characteristics. Late in 1966, however, another worry cropped up.

At a Manned Spacecraft Center senior staff meeting on 4 November, Max Faget reported two instances of unstable combustion: one, during a firing test at White Sands, with a flat-face injector; the second at Bell, during a bomb test for design verification of a supposedly improved, baffled model. In both tests, damages had been extensive. At this point in the program, with the first two flight vehicles already late for delivery, these failures were ominous.³³

Schedule difficulties for the lunar module were nothing new, of course. Grumman had been under the gun from the very beginning, when the mode selection made the lander a late starter in Apollo. But during the summer and autumn of 1966, schedules became crucial. In July, every vehicle on the production line through LM-4 was late. Moreover, because of tardy deliveries by vendors, a serious bottleneck was shaping up in the assembly of LM-1. By late November, however, the earlier remedial actions seemed to be having some good effect and this continual slippage appeared to have slowed. At a briefing for Olin Teague's congressional Subcommittee on NASA Oversight in Houston on 6 October, Shea had said that he expected the first lunar module to be shipped early in 1967.³⁴

By the end of the year, LM-1 and LM-2 were in the test stands at Bethpage, and LM-3 through LM-7 were in various stages of fabrication and equipment installation. But the coming of the new year did not yield the progress Shea had looked for the previous October. Toward the end of January, it was revealed that LM-1 would not reach the Cape in February, as expected.³⁵ In short, the moon landing might be delayed because the lander was not ready. But the mission planners could not wait for the Apollo engineers to iron out all the problems. They had to plan for a landing in 1969 and hope that the hardware would catch up with them.

PLANS AND PROGRESS IN SPACE FLIGHT

In mid-1966, Phillips asked Shea to set up a three-day symposium to review the status of Apollo. At this 25-27 June conference, Phillips requested that the 75 NASA and contractor experts consider carefully such subjects as command and service module maneuvers, lunar module descent and ascent, lunar landing sites, and the length of the visit to the lunar surface.

Shea opened the discussions by listing 23 steps, or rules, in design and operational philosophy (see accompanying list) that had evolved since the lunar-orbit rendezvous decision in 1962. Owen Maynard, deliberately simplifying the many complexities of a lunar mission, described nine plateaus, of which he said:

CHARIOTS FOR APOLLO

It is useful to think of the lunar landing mission as being planned in a series of steps (or decision points) separated by mission "plateaus." . . . The decision to continue to the next plateau is made only after an assessment of the spacecraft's present status and its ability to function properly on the next plateau. If, after such assessment, it is determined that the spacecraft will not be able to function properly, then the decision may be made to proceed with an alternative mission. Alternate missions, therefore, will be planned essentially for each plateau. Similarly, on certain of the plateaus, including lunar stay, the decision may be made to delay proceeding in the mission for a period of time. In this respect, the mission is open-ended and considerable flexibility exists.³⁶

These plateaus, representing the amount of energy expended in going from one step to the next, were widely used by the Apollo engineering team to map the pathway to the moon's surface and back again. The plateaus were, logically, (1) prelaunch, (2) earth parking orbit, (3) translunar coast, (4) lunar orbit before lunar module descent, (5) lunar module descent, (6) lunar surface stay, (7) lunar module ascent, (8) lunar orbit after rendezvous, and (9) trans-earth coast. Breaking the journey into these segments, with identified stopping places, made the Apollo mission seem less complex and fearsome to the planners.

Near the close of the session, Shea commented that all stages of the Saturn V were at Kennedy, preparing for a flight test during 1967; that both the first Block II command and service modules and the lunar module should fly that same year; and that the time for the first lunar mission was rapidly closing in. Shea urged everyone at the meeting to review and comment on current plans and progress.³⁷

It was also time to get an active experiments program under way. Mueller reminded Gilruth that, because of the limitations of 1966-1967 funding, NASA should generate as many of the experiments as possible, instead of relying on contractors. On 14 February 1966, however, Robert O. Piland's Experiments Program Office (established at MSC in the summer of 1965) was asked by Homer Newell, NASA's Associate Administrator for Space Science and Applications, to contract for the development of an Apollo lunar surface experiments package (ALSEP). The following month, the Bendix Systems Division of Ann Arbor, Michigan, received a \$17-million contract to produce four ALSEP units. Bendix was a good choice, having worked with the Jet Propulsion Laboratory on experiments for the unmanned lunar exploration program.³⁸

Getting started on what to take to the moon was fine; getting the facility ready to handle what was brought back from the moon was also important. Houston had to develop a new kind of facility, the Lunar Receiving Laboratory. Its two major jobs would be to protect against back contamination from the moon and to keep the lunar samples as isolated from earthly pollution as possible. Meeting these quarantine and control requirements re-

**Major Considerations in the Design
of the First Lunar Landing Mission**

1. The first Apollo lunar mission will be "open ended," to capitalize on success and keep going as long as possible.
2. Launch will take place on [one of] only three days of any given month.
3. Lighting conditions on the moon at the time of arrival will be a major launch day constraint.
4. The mission will be flexible enough to land at any one of three selected landing sites.
5. Forthcoming information from the first two Orbiters and Surveyor landers will govern site selection.
6. The spacecraft will carry the maximum propellants and consumables that the Saturn V can handle.
7. A slow roll rate will avoid thermal extremes on the spacecraft.
8. The Manned Space Flight Network (MSFN) will be the primary source of navigation data, with onboard navigation as a backup.
9. The service propulsion system will use the lunar module descent engine as a backup.
10. The spacecraft will travel on a free-return trajectory.
11. Landmark sightings by the onboard systems will reduce uncertainties about altitude and tie the MSFN to the moon.
12. Landings will be made in three types of areas—one general and two specific.
13. The crew will be integral to the whole mission, particularly in site selection and landing maneuvers.
14. The first mission will have an 18-hour staytime and two joint excursions by the crew.
15. The LM will use a concentric flight plan for rendezvous with the CSM after liftoff from the moon.
16. If necessary, the CSM will be capable of rescuing the LM by descending to a lower orbit for rendezvous and docking.
17. The prime recovery zone will be in the Pacific Ocean.
18. There will be a continuous abort capability throughout the mission.
19. There will be at least five places during the mission where the spacecraft can "mark time" to change mission planning in case of trouble.
20. Redundant and backup systems will be available for most major systems; significant exceptions are environmental control, electrical power, and service propulsion systems.
21. Continuous communications between spacecraft and ground will be possible, except when the craft is behind the moon or in a thermal roll condition.
22. Design will incorporate reasonable precautions against contamination of either the earth or the moon.
23. Major concerns still remaining are unforeseen environmental effects, calibration of guidance and navigation system, means of realistic simulation of lunar landing under the earth's gravity, and possibility of overloading crew workload.

From Manned Spacecraft Center, "Apollo Lunar Landing Mission Symposium: Proceedings and Compilation of Papers," 25-27 June 1966

CHARIOTS FOR APOLLO

sulted in greater construction costs than initially estimated, but the Space Science Board of the National Academy of Sciences had been adamant in its demands that no expense should be spared:

The introduction into Earth's biosphere of destructive alien organisms could be a disaster of enormous significance to mankind. We can conceive of no more tragically ironic consequence of our search for extraterrestrial life.³⁹

A conference of experts, sponsored by the board in July 1964, had reaffirmed the potential hazards of back contamination and recommended preventive measures. The following year, planning sessions among NASA, the Public Health Service, the Department of Agriculture, and the Army Biological Laboratories mapped out a construction plan and set up precautionary procedures.

Thus, by February 1966, George Low of NASA and James L. Goddard of the Public Health Service had presented Congress with a case for the construction of a lunar sample and quarantine facility with six functions:

1. Microbiology tests of lunar samples to demonstrate to a reasonable degree of certainty the absence of harmful living organisms returned from the lunar surface;
2. Biologically isolated transport of the astronauts and persons required to have immediate contact with them between the recovery area and the quarantine facility;
3. Biological isolation of the astronauts, spacecraft, and other apparatus having a biologic contamination potential, as well as personnel required by mission operations to have immediate contact with these people and this equipment during the quarantine period;
4. Biological isolation during all operations on the samples that must be carried out during the quarantine period;
5. Biologically isolated processing of onboard camera film and data tape that had been exposed to a potentially contaminating environment;
6. Performance of time dependent scientific tests where valuable scientific data would be lost if the tests were delayed for the duration of the quarantine period.⁴⁰

Shortly after congressional approval of the laboratory, Headquarters reluctantly agreed that Houston should manage the design and development of the laboratory without the aid of the Corps of Engineers. Mueller wrote Gilruth on 13 May 1966 that the facility must be ready by November

MOVING TOWARD OPERATIONS

1967 at a cost not to exceed \$9.1 million. Gilruth and Low established a policy board, headed by Faget, and placed Joseph V. Piland in charge of construction. A contract was awarded, ground was broken, and building began in August.⁴¹

During 1966, planners of Apollo's upcoming operational phase studied the results of other programs for information that might be useful. Perhaps the two they scrutinized most carefully were *Gemini VIII*, which proved that one vehicle could find another in space and safely dock with it, and *Surveyor I*, which showed that a craft could land softly on the moon without sinking into the soil—at least in the area of Oceanus Procellarum.

Neil Armstrong and David Scott rode *Gemini VIII* into orbit on 16 March to chase an Agena target vehicle already in flight. An onboard radar acquired the target when the two vehicles were 332 kilometers apart, and the crew members saw the Agena when they were 140 kilometers away. Six hours into the flight, Armstrong and Scott, after inspecting the Agena closely, nudged the nose of their spacecraft into the docking cone, recording the first docking of two vehicles in orbit. Twenty-seven minutes later, Scott's instruments told him that the spacecraft was not in the planned attitude. The docked vehicles then began to gyrate. Armstrong steadied the two craft with the thrusters, and Scott hit the undocking button. Almost immediately, the spacecraft started spinning at the rate of one revolution per second. Armstrong had to use the reentry control system* to straighten out his vehicle. With the help of the flight controllers in Houston and along the Manned Space Flight Network, the crew made a safe emergency landing in the Pacific Ocean—rather than in the Atlantic, as planned.⁴²

Even before Gemini had chalked up the world's first docking, the successful rendezvous of *Gemini VI-A* with *VII* the previous December had affected the thinking of Apollo mission designers. The inability of the Saturn IB to toss the command and service modules and the lunar module into orbit together had forced planners to consider "LM-alone" flights. Gemini's successful dual missions suggested that it might be possible to launch a crew aboard a command module to hunt down a lunar module launched by a different Saturn IB. Two of the crewmen would then transfer to the lander and carry out an earth-orbital operation previously planned for a Saturn V flight.

Although the dual flight for Gemini had been greeted with enthusiasm, the proposal for an Apollo tête-à-tête met with resistance. John D. Hodge, Kraft's chief lieutenant in the mission control trenches, said there would be problems in simultaneously tracking four booster stages and in operating two mission control rooms. Planning continued, anyway, and Howard Tin-

* A separate set of thrusters, used to orient the spacecraft for and to control it during reentry. Mission rules required the landing of the craft as soon as possible after they were fired.

CHARIOTS FOR APOLLO

dall started working up flight rules—such as which launch vehicle would go first, the one with the command and service modules (AS-207) or the one with the lunar module (AS-208). A spate of “Tindallgrams” ensued. By May, Tindall agreed with Hodge about the complexity of the proposed mission.⁴³

While planning proceeded on mission AS-207/208, which seemed to be gaining favor in Washington, the Soviet Union announced on 4 April that *Luna 10* was in lunar orbit—a space first. As the Russian spacecraft sent back information on its voyage around the moon, the United States made its own unmanned lunar exploration spacecraft ready for flight. *Surveyor I*, launched by an Atlas-Centaur from Cape Kennedy on 30 May for a 63-hour trip, was programmed to land softly on the moon to test bearing strength, temperatures, and radar reflectivity and to send television pictures back to the earth. With only slight midcourse corrections, *Surveyor I* flew straight to its target. On 2 June, the vehicle fired its braking rockets, slowing its speed from 9650 kilometers per hour to 640. Four meters above the surface of the crater Flamstead, it was moving at a mere 5.6 kilometers per hour. The three footpads touched safely down within 19 milliseconds of each other.

During the next two weeks, more than 10 000 detailed pictures were transmitted to the Goldstone antenna and processed at the Jet Propulsion Laboratory. They showed rubble scattered over the surface in the Ocean of Storms region. The *Surveyor* craft scanned the horizon and sky better than had been anticipated; its pictures of the stars Sirius and Canopus gave triangulations for its exact location; and its solar cells, radars, computers, and test gear all worked well. The craft did not encounter either hard or porous rock; nor did it find a moon covered by a thick layer of dust. It landed, instead, on a surface composed of finely granulated material with particles that adhered to each other and not to the spacecraft. After all the doubts and waiting, *Surveyor I* demonstrated that a lunar module could land safely on the moon and that its pilots could get out and walk on the surface.⁴⁴

THE ASTRONAUTS AND THE GEMINI EXPERIENCE

Because of the heavy workload in Gemini and the upcoming missions in Apollo, Robert Gilruth had convinced George Mueller the previous year that he needed more astronauts. On 4 April 1966, NASA announced that 19 new flight candidates had been selected, bringing the roster up to 50.* Donald Slayton presided over the corps, selecting and training the crews that were flying Gemini missions almost bimonthly.

* The 19 candidates were Vance D. Brand, John S. Bull, Gerald P. Carr, Charles M. Duke, Jr., Joe H. Engle, Ronald E. Evans, Edward G. Givens, Jr., Fred W. Haise, Jr., James B. Irwin, Don L. Lind, John R. Lousma, Thomas K. Mattingly II, Bruce McCandless II, Edgar D. Mitchell, William R. Pogue, Stuart A. Roosa, John L. Swigert, Jr., Paul J. Weitz, and Alfred M.

MOVING TOWARD OPERATIONS

Preparations for Gemini IX, the second mission scheduled for 1966, began the year in tragedy when its prime crew, Elliot See and Charles Bassett, crashed their aircraft into the building at McDonnell Aircraft Corporation that housed the mission spacecraft. Both were killed. Thomas Stafford and Eugene Cernan took over their duties. On 17 May, an Atlas booster attempted to put an Agena target vehicle into orbit for Gemini and failed. NASA launched a substitute vehicle, called the augmented target docking adapter, on 1 June. Stafford and Cernan were ready to follow, but problems with their guidance system and computer forced them to wait two days before *Gemini IX-A* was launched to start the chase. Once they caught up, they found that the launch shroud had stuck to the substitute target, making it look, as Stafford said, "like an angry alligator." Although hopes for a second docking in space were dashed, Stafford and Cernan carried out rendezvous maneuvers in a variety of ways and Cernan spent two strenuous hours outside of the spacecraft, trying in vain to ride an astronaut maneuvering unit. Apollo mission planners examined these flight results closely, looking for better operations and training procedures, especially for extravehicular activity.⁴⁵

Six weeks after the Stafford-Cernan flight, on 18 July, John Young and Michael Collins pushed off aboard *Gemini X* to rendezvous with a pair of Agenas, one launched for their own mission and the other left in orbit by *Gemini VIII*. They had trouble making the initial rendezvous and used too much fuel; but, once hooked up to their Agena, they found both high-altitude flight, to 763 kilometers, and a meeting with the second Agena fairly simple. Using a hand gun, Collins had such a successful period outside the spacecraft that some NASA officials believed most of the extravehicular problems had been overcome.⁴⁶

But on 12 September, with Charles Conrad at the helm of *Gemini XI*, Richard Gordon found that moving about in space was as difficult as Cernan had said. Gordon became totally exhausted trying to hook a line between the spacecraft and target vehicle so the two craft could separate, spin, and produce a small amount of artificial gravity. He managed to finish the job, but at great physical cost. Nevertheless, *Gemini XI* expanded manned space exploration to a distance of nearly 1400 kilometers above the earth to demonstrate that Apollo spacecraft could travel safely through the trapped radiation zones on their way to the moon. More importantly, perhaps, the crew carried out a first-orbit rendezvous, to simulate the lunar module lifting off the moon to meet the command module in lunar orbit, and made the first computer-controlled reentry. Conrad checked his onboard data with mission control, cut in his computer, and flew in on what amounted to an automatic

Worden. Actually this fifth set brought the total selected to 55, but the number on active status had been reduced for a variety of reasons: John Glenn had resigned to pursue a political and business career; Scott Carpenter had returned to duty in the Navy; and Charles Bassett, Theodore Freeman, and Elliot See had been killed in aircraft accidents.

CHARIOTS FOR APOLLO

pilot—much as Apollo crews would have to do to hit the narrow reentry corridor on their return to earth.⁴⁷

In the Gemini finale, NASA was intent on eliminating some of the mystery of why man's work outside his spacecraft was so difficult. In preparation for this, the astronauts began underwater training, which simulated extravehicular activity more closely than the few seconds of weightlessness that could be obtained during Keplerian trajectories in aircraft. The pilot-controlled maneuvering unit was canceled after Gordon's difficulties, so the *Gemini XII* crew could concentrate on the "fundamentals" of extravehicular movements. When James Lovell and Edwin Aldrin left the ground on 11 November, this was really the chief objective of their mission. By this time, crew systems personnel had attached enough rails and handholds here and there about the spacecraft to give Aldrin a relatively easy five hours of work outside the spacecraft.⁴⁸

Gemini made major contributions to Apollo and to the astronauts. Flight control and tracking network personnel learned to conduct complex missions with a variety of problems, and mission planners understood more about what it would take to land men on the moon. Rendezvous was demonstrated in so many ways that few engineers remembered they had ever thought it might be difficult. Perhaps the biggest gain for the astronauts was that 16 of the 50 had flown, operated controls, and performed experiments in the weightlessness of space.

Apollo astronauts, however, would rely more on simulators than on Gemini experience. There were, or soon would be, three sets of these trainers—two at Cape Kennedy and one in Houston—modeled after the command module and the lunar module. The simulators, constantly being changed to match the cabin of each individual spacecraft, were engineered to provide their riders with all the sights, sounds, and movements they would encounter in actual flight. Slayton had told George Mueller that the crews would need 180 training hours in the command module simulator and the flight commander and lunar module pilot an additional 140 hours in the lunar module trainer—about 80 percent more training time than the pilots of the early Gemini flights had required.⁴⁹

PREPARATIONS FOR THE FIRST MANNED APOLLO MISSION

For a time, the mission called AS-204 had two flight plans. AS-204A, manned by Gus Grissom, Edward White, and Roger Chaffee,* was "to verify spacecraft/crew operations and CSM subsystems performance for an earth-orbit mission of up to 14 days' duration and to verify the launch vehicle

* NASA announced 21 March 1966 that these three astronauts would fly the first manned Apollo mission.

MOVING TOWARD OPERATIONS

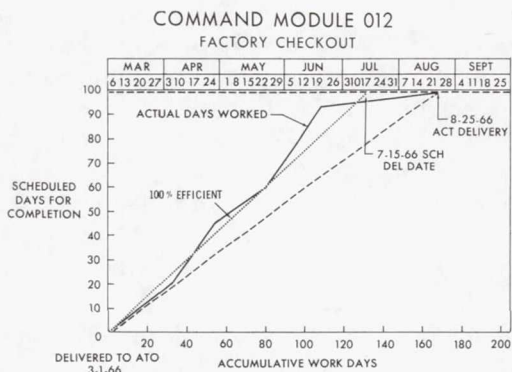
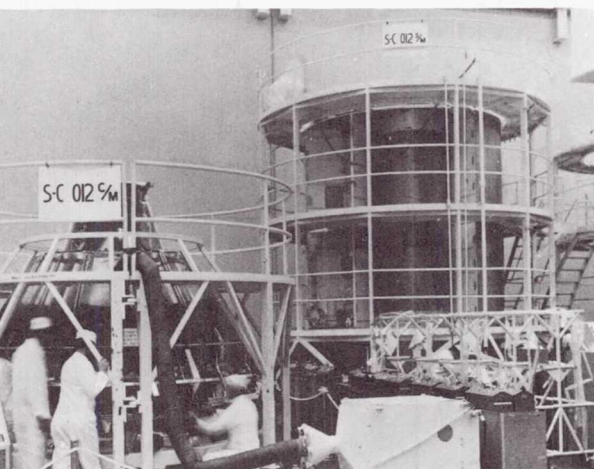
subsystems performance in preparation for subsequent operational Saturn IB missions." The flight would be in the last quarter of 1966 from Launch Complex 34 at Cape Kennedy. AS-204B, on the other hand, would be an unmanned mission with the same objectives (except for crew operations), to be flown only if spacecraft and launch vehicle had not qualified for manned flights. And there were doubts. Gas ingestion in the service module propulsion system in AS-201 and the resulting erratic firing had caused some misgivings, although these had been somewhat allayed by AS-202.⁵⁰

As in early Mercury and Gemini manned flights, stress was laid on engineering and operational qualification rather than on experiments—whether medical or scientific. In December 1966, with only 9 experiments assigned to AS-204, 30 operational functions had a higher priority. And even then Slayton complained that the crew was not getting enough time in the new simulation and checkout facilities because of the experiments. Despite his arguments, the second Apollo crew (Walter Schirra, Donn Eisele, and Walter Cunningham, with Frank Borman, Stafford, and Collins as backups), announced on 29 September, was scheduled for a heavier workload of experiments.⁵¹ As technical troubles came to the fore, however, emphasis on experiments shifted.

North American should have shipped spacecraft 012 from Downey to Kennedy in early August, but "eleventh hour problems associated with the Command Module Environmental Control Unit water glycol pump failure resulted in a NAA/NASA decision to replace the ECU with the unit from SC 014." The Customer Acceptance Review revealed some environmental control items that still needed to be corrected, but NASA allowed North American to ship 012 to Florida on 25 August anyway. Once it arrived, John G. Shinkle, Apollo Program Manager at Kennedy, complained about the amount of engineering work that still had to be done. More than half of it, he said, should have been finished before the spacecraft left the factory.⁵²

While flight-preparation crews were having problems, Grissom, White, and Chaffee were finding bottlenecks in training activities. The chief problem was keeping the Apollo mission simulator current with changes being made in spacecraft 012. At the Cape, Riley D. McCafferty said, there were more than 100 modifications outstanding at one time. Grissom, McCafferty later recalled, would "tear my heart out" because the simulator was not keeping up with the spacecraft. Eventually, the first Apollo commander hung a lemon on the trainer.⁵³

Getting the spacecraft to the Cape did not really improve conditions. The environmental control unit needed to be replaced again, which held up testing in the vacuum chamber. AiResearch shipped the new unit from its West Coast plant to Kennedy on 2 November. Within two weeks, it was installed and testing was begun. It was then returned to California for further work. By mid-December, the component was back in Florida and in the



Command module 012 and service module 012 (upper left) in workstands at the North American Aviation plant, Downey, in 1965. The chart shows the factory checkout workdays (1966). At left, CM-012—"Apollo One"—arrives at Kennedy Space Center, 26 August 1966. Below, astronauts Grissom (left), Chaffee, and White check the communications headgear in preparation for what was to have been the first manned Apollo flight—Apollo-Saturn 204, scheduled for 21 February 1967.



spacecraft. Meanwhile, the service module had been waiting in the vacuum chamber for the command module. While it was sitting there, a light shattered, and falling debris damaged several of the maneuvering thrusters.⁵⁴ But this was not the only cause for worry about the service module.

On 25 October at the North American factory, the service module for spacecraft 017 was undergoing routine pressure tests of the propulsion system's propellant tanks when the tanks suddenly exploded. No one was injured, but North American and NASA engineers were baffled as to the cause for the next few weeks. The tanks had not been overpressurized, test procedures had not been relaxed, and no design deficiencies were apparent; yet the fuel storage tank had failed with a bang. Since the service module for spacecraft 012 had been through identical tests, Shea was vitally concerned with unraveling this riddle before Grissom and his group flew.

William M. Bland and Joseph N. Kotanchik were sent from the Manned Spacecraft Center to Downey to help North American hunt for the trouble, and Houston set up a parallel test to verify the results. They learned that the methanol (methyl alcohol) employed as a test pressurant fluid caused stress corrosion (or cracking) of the titanium alloy used for the propellant tanks. Replacing the methanol with a fluid that was compatible with titanium would eliminate this problem. In the meantime, the tanks were removed from service module 012 and found to be free of any dangerous corrosion.⁵⁵

In September, Mueller reminded Gilruth of the upcoming Design Certification Review. Board membership would, he said, include himself, Gilruth, von Braun, and Debus. The group met on 7 October and agreed that the space vehicle conformed to design requirements and was flightworthy, provided several deficiencies were corrected. Phillips sent the list to Lee B. James at Marshall, Shinkle at Kennedy, and Shea at the Manned Spacecraft Center, urging speedy clearance. Shinkle had already registered his complaints about spacecraft 012; now he added that Houston should insist on better spacecraft being shipped to the Cape. He pointed out the major problems that had been found: a leak in the service propulsion system, problems with the reaction control system, troubles in the environmental control unit, and even design deficiencies in the crew couches that required North American engineers to travel from Downey to the Cape to correct them.⁵⁶

In early December, NASA reluctantly surrendered its plans for launching the first manned Apollo flight before the end of 1966. Mueller and Seamans then reshuffled the flight schedule, delaying AS-204 until February 1967 and scrubbing the scheduled second mission. Experimenters who had planned to place their wares aboard Schirra's spacecraft were brushed aside. Following AS-204, NASA planned to fly the lunar module alone and then a manned Block II command and service module, No. 101, in August 1967 to rendezvous with unmanned LM-2, the LM being lofted into orbit by a Saturn IB in a mission dubbed AS-205/208.

CHARIOTS FOR APOLLO

If everything went well, NASA hoped to get two crews besides Grissom's spaceborne before the end of 1967, with at least one riding a Saturn V. Replacing the Schirra team as the second Apollo flight crew were James McDivitt, David Scott, and Russell Schweickart (backed by Thomas Stafford, John Young, and Eugene Cernan) for a workout of the command module and lander in earth orbit. To fly the Saturn V mission, AS-503, NASA picked Frank Borman, Michael Collins, and William Anders (with Charles Conrad, Richard Gordon, and Clifton Williams as backups); they would ride the spacecraft into orbit and out as far as 6400 kilometers above the earth.⁵⁷

After all this flight shuffling, the Apollo program seemed to be in fair shape at the end of 1966. North American had finished the last of the manufacturing work on the earth-orbital version of the command and service modules on 16 September and could now concentrate on improving the lunar-orbital spacecraft.⁵⁸ The lunar module still had problems, but Grumman was making headway in resolving them. The pathway to the moon appeared to be clearing, as NASA stood on the threshold of Apollo manned space flight operations.

9

Tragedy and Recovery

1967

Nestled beside an umbilical tower, surrounded by a service structure, and encased in a clean room at Cape Kennedy's Launch Complex 34, spacecraft 012 sat atop a Saturn IB on Friday morning, 27 January 1967. Everything was ready for a launch simulation, a vital step in determining whether the spacecraft would be ready to fly the following month. During this "plugs out" test, all electrical, environmental, and ground checkout cables would be disconnected to verify that the spacecraft and launch vehicle could function on internal power alone after the umbilical lines dropped out.¹

By 8:00 that morning, a thousand men, to support three spacesuited astronauts—Virgil Grissom, Edward White, and Roger Chaffee—were checking systems to make sure that everything was in order before pulling the plugs. In the blockhouse, the clean room, the service structure, the swing arm of the umbilical tower, and the Manned Spacecraft Operations Building, this army of technicians was to go through all the steps necessary to prove that this Block I command module was ready to sustain three men in earth-orbital flight. Twenty-five technicians were working on level A-8 of the service structure next to the command module and five more, mostly North American employees, were busy inside the clean room at the end of the swing arm. Squads of men gathered at other places on the service structure. If interruptions and delays stretched out the test, as often happened, round-the-clock shifts were ready to carry the exercise to a conclusion. Throughout the morning, however, most of the preparations went smoothly, with one group after another finishing checklists and reporting readiness.

CHARIOTS FOR APOLLO

After an early lunch, Grissom, White, and Chaffee suited up, rode to the pad (arriving an hour after noon), and slid into the spacecraft couches. Technicians sealed the pressure vessel inner hatch, secured the outer crew access hatch, and then locked the booster cover cap in place. All three astronauts were instrumented with biomedical sensors, tied together on the communications circuit, and attached to the environmental control system. Strapped down, as though waiting for launch, they began purging their space suits and the cabin atmosphere of all gases except oxygen—a standing operating procedure.²

STALKED BY THE SPECTRE

For almost a year, the Grissom crew had watched its craft go through the production line, test program, and launch pad preparations. After participating in a multitude of critiques, reading numerous discrepancy reports, and going through several suited trials in the spacecraft in altitude chambers at Downey and the Cape, Grissom's group had learned almost all the idiosyncracies of spacecraft 012. The astronauts knew, if not every nut and bolt, at least the functions of its 88 subsystems and the proper positions for hundreds of switches and controls inside the cockpit. They also knew that the environmental unit had been causing trouble. Indeed, Grissom's first reports on entering the cabin were of a peculiar odor—like sour milk.*³

As all traces of sea-level atmosphere were removed from the suit circuit and spacecraft cabin, pure oxygen at a pressure of 11.5 newtons per square centimeter (16.7 pounds per square inch) was substituted. The crew checked lists, listened to the countdown, and complained about communications problems† that caused intermittent delays. The men could speak over four channels, either by radio or telephone line, but the tie-in with the test conductors and the monitors was complicated and troublesome. Somewhere there was an unattended live microphone that could not be tracked down and turned off. Other systems, Grissom's crew noted, seemed to be operating normally. At four in the afternoon, one shift of technicians departed and another came on duty.

Near sunset, early on this winter evening, communications problems again caused a delay, this time for ten minutes, before the plugs could be pulled. Thus, the test that should have been finished had not really started,

* More than a week earlier, in an altitude chamber test at the Cape, the crewmen had complained that their eyes had smarted when they plugged the suit circuit into the environmental control unit.

† Earlier in January, Douglas Broome of the Apollo office in Houston had recommended using heavier wire in the communications systems. The size North American had installed in spacecraft 012, he said, was too flimsy and too subject to damage.

TRAGEDY AND RECOVERY

and an emergency egress practice was still to come. The crew was accustomed to waiting, however, having spent similar long hours in trouble-plagued training simulators. About 6:30, Grissom may have been thinking about the jest he had played on Riley McCafferty by hanging a lemon on the trainer.⁴

Donald Slayton sat half a kilometer away at a console in the blockhouse next to Stuart Roosa, the capsule communicator.* On the first floor of the launch complex, Gary W. Propst, an RCA employee, watched a television monitor that had its transmitting camera trained on the window of the command module. Clarence A. Chauvin, the Kennedy Space Center test conductor, waited in the automated checkout equipment room of the operations building, and Darrell O. Cain, the North American test conductor, sat next door. NASA quality control inspector Henry H. Rogers boarded the Pad 34 elevator to ride up to the clean room. There, at the moment, were three North American employees: Donald O. Babbitt, pad leader; James D. Gleaves, mechanical technician; and L. D. Reece, systems technician. Reece was waiting to pull the plugs on signal. Just outside on the swing arm, Steven B. Clemmons and Jerry W. Hawkins were listening for Reece to call them to come and help. All of these men and several others in the vicinity at 6:31 heard a cry over the radio circuit from inside the capsule: "There is a fire in here."⁵

Stunned, pad leader Babbitt looked up from his desk and shouted to Gleaves: "Get them out of there!" As Babbitt spun to reach a squawk box to notify the blockhouse, a sheet of flame flashed from the spacecraft. Then he was hurled toward the door by a concussion. In an instant of terror, Babbitt, Gleaves, Reece, and Clemmons fled. In seconds they rushed back, and Reece and Clemmons searched the area for gas masks and for fire extinguishers to fight little patches of flame. All four men, choking and gasping in dense smoke, ran in and out of the enclosure, attempting to remove the spacecraft's hatches.

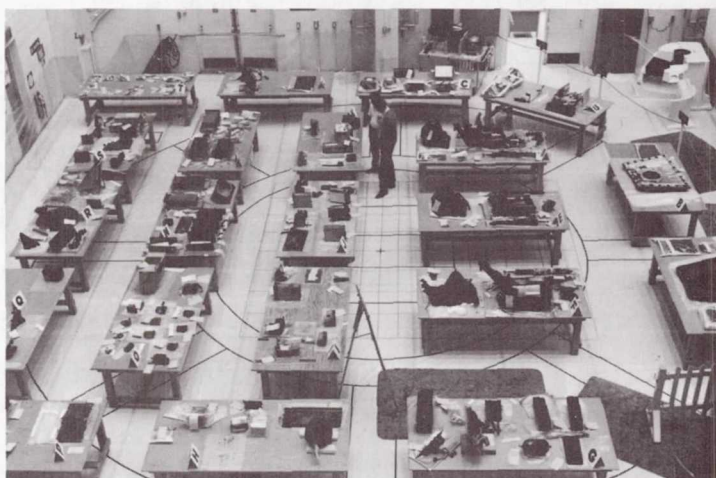
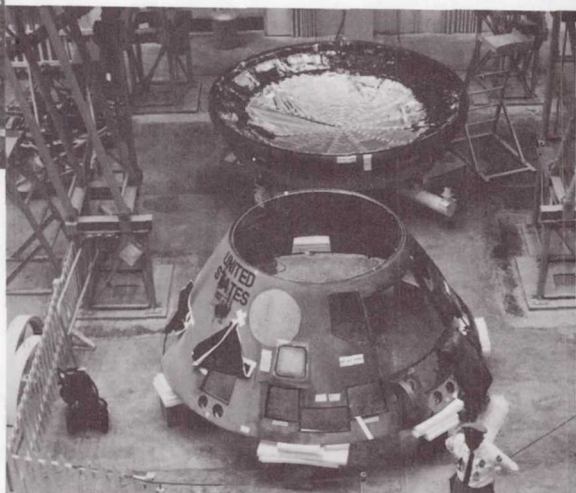
Meanwhile, Propst's television picture showed a bright glow inside the spacecraft, followed by flames flaring around the window. For about three minutes, he recalled, the flames increased steadily. Before the room housing the spacecraft filled with smoke, Propst watched with horror as silver-clad arms behind the window fumbled for the hatch. "Blow the hatch, why don't they blow the hatch?" he cried. He did not know until later that the hatch could not be opened explosively.† Elsewhere, Slayton and Roosa watched a

* Both Slayton and Joseph Shea had thought of joining the crew in the spacecraft to participate in the test so they could get more feel for actual operations. This was not an unusual procedure, but the time for the scheduled launch was too near. Instead, Shea had flown back to Houston, and Slayton had elected to sit with the CapCom and watch.

† After the loss of Grissom's spacecraft in Mercury, when a faulty mechanism blew the hatch prematurely, Space Task Group designers had gone from an explosive to a mechanically operated hatch. This practice continued in Gemini and Apollo.



The environmental control system's instrumentation harness (above) after the command module 012 fire that took the lives of Grissom, White, and Chaffee on 27 January 1967. CM-012 was disassembled for the investigation; the crew compartment heatshield (foreground) and aft heatshield are displayed at right above. CM parts were studied and catalogued in the Pyrotechnics Installation Building at Kennedy Space Center (below).



television monitor, aghast, as smoke and fire billowed up. Roosa tried and tried to break the communications barrier with the spacecraft, and Slayton shouted furiously for the two physicians in the blockhouse to hurry to the pad.⁶

TRAGEDY AND RECOVERY

In the clean room, despite the intense heat, Babbitt, Gleaves, Reese, Hawkins, and Clemmons, now joined by Rogers, continued to fight the flames. From time to time, one or another would have to leave to gasp for air. One by one, they removed the booster cover cap and the outer and inner hatches—prying out the last one five and a half minutes after the alarm sounded. By now, several more workers had joined the rescue attempt. At first no one could see the astronauts through the smoke, only feel them. There were no signs of life. By the time firemen arrived five minutes later, the air had cleared enough to disclose the bodies. Chaffee was still strapped in his couch, but Grissom and White were so intertwined below the hatch sill that it was hard to tell which was which. Fourteen minutes after the first outcry of fire, physicians G. Fred Kelly and Alan C. Harter reached the smoldering clean room. The doctors had difficulty removing the bodies because the spacesuits had fused with molten nylon inside the spacecraft.

As anguished officials gathered, the pad was cleared of unnecessary personnel, guards were posted, and official photographers were summoned. All through the night, physicians labored to complete their grim task. After the autopsies were finished, the coroner reported that the deaths were accidental, resulting from asphyxiation caused by inhalation of toxic gases. The crew did have second and third degree burns, but these were not severe enough to have caused the deaths.⁷

Most persons who had been connected with the space program in any way remember that the tragedy caught them by surprise. In six years of operation, 19 Americans had flown in space (7 of them, including Grissom, twice) without serious injury. Procedures and precautions had been designed to foresee and prevent hazards; now it was demoralizing to realize the limits of human foresight. Several other astronauts had died, but none in duties directly associated with space flight. Airplane crashes had claimed the lives of Elliot See, Charles Bassett, and Theodore Freeman. These were traumatic experiences, but the loss of three men during a ground test for the first manned Apollo flight was a more grievous blow.

Memorial services for the AS-204 crewmen were held in Houston on 30 January, although their bodies had been flown north from Kennedy for burial. Grissom and Chaffee were buried in Arlington National Cemetery and White at the Military Academy at West Point. Amid these last rites, a similar tragedy took the lives of two men in an oxygen-filled chamber at Brooks Air Force Base in San Antonio. Airman 2/c William F. Bartley and Airman 3/c Richard G. Harmon were drawing blood samples from rabbits when a fire suddenly swept through the enclosure. The spacecraft and chamber tragedies pinpointed the dangers inherent in advanced space-simulation work.⁸

The accident that took the lives of Grissom, White, and Chaffee was heartrending, and some still insist totally unnecessary; but NASA had always feared that, in manned space flight, danger to pilots could increase with

CHARIOTS FOR APOLLO

each succeeding program. Space flight officials had warned against undue optimism for years, pointing out that any program that large inevitably took its toll of lives—from accident, overwork, or illness brought on by the pressures of such an undertaking. Man was fallible; and a host of editorial cartoons reiterated this axiom for several months after the fire. One, by Paul Conrad in the *Los Angeles Times*, showed the spectre of death clothed in a spacesuit holding a Mercury spacecraft in one hand, a Gemini in the other, and with the smoldering Apollo in the background. It was captioned, "I thought you knew, I've been aboard on every flight."⁹

While preaching the need to promote quality workmanship, NASA managers had relied on their contractors to invoke effective measures. NASA executives knew they had tried to inspire the whole Apollo team to strive for perfection, but the haunting question now was: Had they tried hard enough? Every company and organization had a management scheme to increase personal motivation by giving recognition to faultless performance. North American had its "PRIDE" program, standing for "Personal Responsibility in Daily Effort," and NASA had "MFA" for "Manned Flight Awareness." The NASA program also featured what was called the "Lunar Roll of Honor"; the first lunar landing party would carry a microfilm listing 300 000 names, honoring the exceptional service of those who had aided significantly in the achievement. After the fire, the idea was dropped. Just as it became obvious how difficult it was to fix the blame for failure, it would later be come apparent that it would be equally hard to pinpoint responsibility for success.¹⁰

In Washington on the day of the accident, an Apollo Executives' Conference was in session, attended by NASA leaders James Webb, Robert Seamans, and George Mueller and by top Gemini and Apollo corporate officials, to mark the transition from two- to three-man space flight operations. That morning the conferees had been invited to the White House to witness the signing of a space treaty. President Johnson described this event as the "first firm step toward keeping outer space free forever from the implements of war." Later, as the tragic news from Pad 34 spread, the executives considered disbanding. Administrator Webb, however, decided to carry on; Mueller would stay in Washington and Seamans and Samuel Phillips would go to the Cape. The next day, Mueller reported the first few meager facts to the meeting and then gave a paper that Phillips had intended to present. Ironically, Phillips had listed troubles with quality assurance among the top ten problems faced in Apollo.¹¹

THE INVESTIGATION

After the fire, amid all the grief and the shock that it could have happened, a thorough fact-finding investigation was conducted. Webb and Sea-

TRAGEDY AND RECOVERY

mans asked Floyd L. Thompson, Director of Langley Research Center, to take charge of the inquiry. Thompson and Seamans met at Kennedy at noon on 28 January for a brief session with other Headquarters, Houston, and Cape officials and then adjourned to Complex 34 to see the scene of the accident.¹²

Seamans returned to Washington that evening, consulted with Webb, and drafted a memorandum formalizing the AS-204 Review Board with Thompson as chairman. Members were astronaut Frank Borman and Max Faget of the Manned Spacecraft Center, E. Barton Geer of Langley Research Center, George W. Jeffs of North American, Franklin A. Long of Cornell University and the President's Science Advisory Committee, Colonel Charles F. Strang of the Air Force Inspector General's office, George C. White of NASA Headquarters, and John J. Williams of Kennedy Space Center.

The board quickly established tight security at Complex 34, impounded documents pertaining to the accident, and collected eyewitness reports. News media representatives swarmed in to cover the story, and their unofficial investigations and semifactual innuendos filled newsprint and airwaves throughout the following weeks. Many looked for quick answers and simple explanations, but by 3 February it was obvious to NASA officials, at least, that no single cause for the accident could be isolated immediately. Seamans and Thompson set up 21 panels to assist the review board. When he realized that full-time participation was expected, Long asked to be excused. He was replaced by Robert W. Van Dolah, an explosives expert from the Bureau of Mines. In other personnel actions, Seamans asked Jeffs to serve as a consultant rather than as a board member and George T. Malley, chief counsel at Langley, to act as legal advisor.¹³

Anticipating public clamor for answers and reforms, if not postponement of Apollo, NASA officials asked leading members of Congress to hold off on a full-scale investigation until the review board finished its report. Senator Clinton P. Anderson, Chairman, agreed to call the Senate Committee on Aeronautical and Space Sciences into executive session only, for its early investigations. And Representative George P. Miller, Chairman of the House Committee on Science and Astronautics, said Olin Teague's Subcommittee on NASA Oversight would not begin hearings until the Thompson Board had submitted its report. Many newsmen charged that the full story would never be known, since most of the board members were NASA employees; others conjectured that Apollo might be grounded altogether. Meanwhile, the Apollo 204 Review Board went systematically about its business.¹⁴

Seamans returned to Florida on 2 February to prepare a preliminary report for Webb. Although this was made public just a few days later, accusations still swirled that the NASA investigation could not be impartial since it was a probe of the agency by itself. There were also sensationalistic charges such as those in Eric Bergaust's book, *Murder on Pad 34*, a year and

CHARIOTS FOR APOLLO

a half later. Bergaust said that NASA, even while denying that it was in a space race, had nevertheless placed speed above safety.¹⁵

But there was plenty of evidence that meeting schedules was not the whole story. "We're in a risky business," Grissom himself had said in an interview several weeks before the fire, "and we hope if anything happens to us, it will not delay the program. The conquest of space is worth the risk of life." He was later quoted as saying, "Our God-given curiosity will force us to go there ourselves because in the final analysis only man can fully evaluate the moon in terms understandable to other men."¹⁶

Congressional leaders did not entirely share the views and misgivings of the press. In a bipartisan move, Senators Anderson and Margaret Chase Smith arranged for publication of the executive hearings of 7 February with Seamans, Mueller, Charles A. Berry (Houston's medical director of manned space flight), and Richard Johnston (spacesuit and life support systems expert). This openness of congressional deliberations helped to defuse media criticism about the objectivity of the ongoing investigation.¹⁷

Spacecraft 014, nearly identical to 012, was shipped from California to Florida. There the Thompson Board and its panels had the vehicle dismantled for comparison with the remains of 012, which was being taken apart and every piece studied and analyzed. Thompson took advantage of the background and experience of his board members, assigning some to monitor several of the panels. While technicians worked around the clock for the first few weeks, the board held daily recorded and transcribed sessions to consider the findings. Strang was an effective vice-chairman, drawing on his background as an inspector to organize proceedings and prepare comprehensive reports. Van Dolah, the mining explosives expert, had only one panel—origin and propagation of the fire—to monitor, emphasizing the importance of finding that answer. Thompson reserved a single panel, medical analysis, for himself.

Faget had the heaviest load of panels: sequence of events, materials review, special tests, and integration analysis. Borman drew the teams on disassembly, ground emergency provisions, and inflight fire emergency provisions. Williams monitored the spacecraft and ground support equipment configuration, test procedures review, and service module disposition. George White, quality and reliability chief from Headquarters, was responsible for investigations into test environments, design reviews, and historical data. An associate of Thompson's from Langley, Geer handled the groups on the analysis of spacecraft fractures, the board's administrative procedures, and the safety of the investigation operations themselves. Strang was left with the panels taking statements from witnesses, handling the security operations of the inquiry, and writing up the final report.

When Seamans made a second preliminary report to Webb, on 14 February, it was clear that the fire was indeed a fire, and not an explosion leading to a fire. Physical evidence indicated that the conflagration had passed

TRAGEDY AND RECOVERY

through more than one stage of intensity before the oxygen inside the cabin was used up. By mid-February, the work of tearing down the command module had reached a point where a two-shift six-day week could replace round-the-clock operations.

On the day of the scheduled launch of AS-204, 21 February, the board gave a preliminary briefing to George Mueller and a dozen other top NASA officials in preparation for a major briefing of Seamans. Thompson told Seamans the next day that 1500 persons were directly supporting the investigation—600 from government and 900 from industry and the universities—and that the board planned to complete its report by the end of March. Although the history of the fire after it started had been minutely reconstructed, the specific source of ignition had not been—and might never be—determined. On 25 February, Seamans prepared a memorandum for Webb, listing early recommendations by the board that the Administrator could present to Congress:

That combustible materials now used be replaced wherever possible with non-flammable materials, that non-metallic materials that *are* used be arranged to maintain fire breaks, that systems for oxygen or liquid combustibles be made fire resistant, and that full flammability tests be conducted with a mockup of the new configuration.

That a more rapidly and more easily operated hatch be designed and installed.

That on-the-pad emergency procedures be revised to recognize the possibility of cabin fire.¹⁸

The astronaut member of the Thompson Board assured NASA's top officials that he would not have been afraid to enter the Grissom crew's spacecraft that January day. Working with the board, however, Borman and everyone else had come to realize the substantial hazards that had been present but not recognized before the fire.¹⁹

As its final report was being put together, the review board recognized that there had been ignorance, sloth, and carelessness, but the key word in all the detailed information was "oversight." No one, it seemed, realized the extent of fire hazards in an overpressurized oxygen-filled spacecraft cabin on the ground, according to the summary report the board issued on 5 April:

Although the Board was not able to determine conclusively the specific initiator of the Apollo 204 fire, it has identified the conditions which led to the disaster. . . : 1. A sealed cabin, pressurized with an oxygen atmosphere. 2. An extensive distribution of combustible materials in the cabin. 3. Vulnerable wiring carrying spacecraft power. 4. Vulnerable plumbing carrying

CHARIOTS FOR APOLLO

a combustible and corrosive coolant. 5. Inadequate provisions for the crew to escape. 6. Inadequate provisions for rescue or medical assistance.

Having identified the conditions that led to the disaster, the Board addressed itself to the question of how these conditions came to exist. Careful consideration of this question leads the Board to the conclusion that in its devotion to the many difficult problems of space travel, the Apollo team failed to give adequate attention to certain mundane but equally vital questions of crew safety. The Board's investigation revealed many deficiencies in design and engineering, manufacture and quality control.²⁰

The Thompson Board report came to almost 3000 pages; divided into 14 booklets, it made up a stack about 20 centimeters high. The six appendixes were: (A) the minutes of the board's own proceedings; (B) eyewitness statements and releases; (C) the Operations Handbook for spacecraft 012; (D) final reports of all 21 panels; (E) a brief summary of management and organization; and (F) a schedule of visible evidence.

But even before the board issued its report, its conclusions were essentially already public. For instance, a month after the fire Mueller had admitted to Congress that, after six safe years of manned flight experience, it was now obvious that NASA's approach to fire prevention had been wrong. Minimizing the possibility of ignition had not been enough. Safeguards against the spreading of any fire must also be developed. Since it would be nearly impossible to design equipment that would protect the crews both on the ground and in space,* any nonmetallic, and perhaps flammable, materials would have to be carefully screened. In particular, the "four Fs"—fabrics, fasteners, film, and foams—required further investigation. Wiring, plumbing, and packaging must be reevaluated, even if it meant reviving the old debate about a one- versus two-gas environmental control system.²¹

As they delved deeper into the reasons behind the tragedy, NASA officials were confronted by some "skeletons in their closet." Senator Walter F. Mondale raised the question of negligence on the part of management and the prime contractor by introducing the "Phillips report" of 1965–1966. The implication was that NASA had been thinking of replacing North American. But the charges were vague; and, for the next several weeks, no one seemed to know exactly what the Phillips report was. In fact, Webb at first denied that there was such a report. (See Chapter 8.) Mondale also alluded to a document by a North American employee, Thomas R. Baron, that was

* In August 1966, three fire extinguishers, weighing only 5.7 to 6 kilograms, were evaluated for spacecraft 012 and subsequent flights. The extinguisher selected would be stowed on liftoff for the first manned flights. On later missions, it would be mounted in brackets. All three used Freon FE 1301, a most efficient extinguishing agent on the ground. Under space conditions, however, the chemical worked more slowly, required a higher level of saturation of the flammable materials, and, even worse, generated a gas that might, in sufficient quantities, prove fatal to the crew. Other chemicals would of course be tested, but this would take time.

critical of the contractor's operations at the Cape.

Baron was a rank and file inspector at Kennedy from September 1965 until November 1966, when he asked for and received a leave of absence. He had made observations; had collected gossip, rumor, and critical comments from his fellow employees; and had written a set of condemnatory notes. He had detailed, but not documented, difficulties with persons, parts, equipment, and procedures. Baron had observed the faults of a large-scale organization and apparently had performed his job as a quality inspector with a vengeance. He noted poor workmanship, spacecraft 012 contamination, discrepancies with installations, problems in the environmental control system, and many infractions of cleanliness and safety rules.

Baron passed on these and other criticisms to his superiors and friends; then he deliberately let his findings leak out to newsmen. North American considered his actions irresponsible and discharged him on 5 January 1967. The company then analyzed and refuted each of Baron's charges and allegations. In the rebuttal, North American denied anything but partial validity to Baron's wide-ranging accusations, although some company officials later testified before Congress that about half of the charges were well-grounded. When the tragedy occurred, Baron was apparently in the process of expanding his 55-page paper into a 500-page report.

When his indictments were finally aired before Teague's subcommittee, during a meeting at the Cape on 21 April, Baron's credibility was impaired by one of his alleged informants, a fellow North American employee named Mervin Holmburg. Holmburg denied knowing anything about the cause of the accident, although Baron had told the committee that Holmburg "knew exactly what caused the fire." Holmburg testified that Baron "gets all his information from anonymous phone calls, people calling him and people dropping him a word here and there. That is what he tells me." Ironically, Baron and all his family died in a car-train crash only a week after this exposure to congressional questioning.²²

Beyond the Phillips and Baron reports, however, recollections of events and warnings during the past six years made each Apollo manager wonder if he had really done all in his power to prevent the tragedy. In March 1965, for instance, Shea and the crew systems people in Houston had wrestled with the question of the one- or two-gas atmosphere and the likelihood of fire—most of the studies were, admittedly, based on the possibility of fire in space—and concluded that a pure oxygen system was safer, less complicated, and lighter in weight. The best way to guard against fire was to keep flammable materials out of the cabin. Hilliard W. Paige of General Electric had, as a matter of fact, warned Shea about the likelihood of spacecraft fires on the ground as recently as September 1966; and, just three weeks before the accident, Medical Director Charles Berry had complained that it was certainly harder to eliminate hazardous materials from the Apollo spacecraft than it had been in either Mercury or Gemini.²³

CHARIOTS FOR APOLLO

Although the Senate committee had begun its hearings while the board investigation was in progress, the House subcommittee waited until the final report was ready. By then, the Senate had touched on most of the major issues. As expected, the exact cause of the fire in spacecraft 012 was never determined, but the analysis of all possibilities led to specific corrective actions that eventually satisfied Congress. Throughout the hearings, Borman, still wearing two hats—as an astronaut and as a member of the Apollo 204 Review Board—was very effective. In the course of his testimony, Borman reiterated that the cause of the fire was oversight, rather than negligence or overconfidence. Fire in flight, he said, had been a matter of grave concern since the early days of aviation and the subject of numerous studies. But the notion that a fire hazard was increased on the ground by the use of flammable materials and an overpressure of pure oxygen had never been seriously considered.

On one occasion, when astronauts Walter Schirra, Slayton, Alan Shepard, and James McDivitt had expressed their confidence in NASA's future safety measures, Borman answered a congressman's doubts by saying:

You are asking us do we have confidence in the spacecraft, NASA management, our own training, and . . . our leaders. I am almost embarrassed because our answers appear to be a party line. Everything I said last week has been repeated by the people I see here today. The response we have given is the same because it is the truth. . . . We are trying to tell you that we are confident in our management, and in our engineering and in ourselves. I think the question is really: Are you confident in us?²⁴

When Borman made a plea on 17 April to stop the witch hunt and get on with Apollo, both NASA and North American had responded to the criticisms of the Thompson Board and of Congress. Top-level personnel changes were direct outgrowths of the charges of negligence and mismanagement: Everett E. Christensen at NASA Headquarters resigned as Apollo mission director; George Low replaced Shea as Apollo Spacecraft Program Manager in Houston; and William D. Bergen (formerly of the Martin Company) took over from Harrison Storms as president of North American's Space and Information Systems Division. Bergen brought with him two associates from Martin: Bastian Hello to run the Florida facility for North American and John P. Healy to manage the first manned Block II command module at Downey. Healey was expected to set precedents in guiding a nearly perfect spacecraft through the factory.²⁵

Most North American officials weathered congressional criticism and pointed out that they agreed, in part, with the formal findings and recommendations of the Thompson Board.* But North American objected to the

* The widows of Grissom, White, and Chaffee sued North American for negligence in spacecraft manufacture. In 1972, out-of-court settlements to the three totaled \$650 000.

word "chronic" in describing problems with the environmental control system and defended its electrical wiring practices as functional rather than beautiful. Concurring that the fire probably started from an electrical spark somewhere near the environmental unit, the manufacturers also agreed with NASA on why the fire spread:

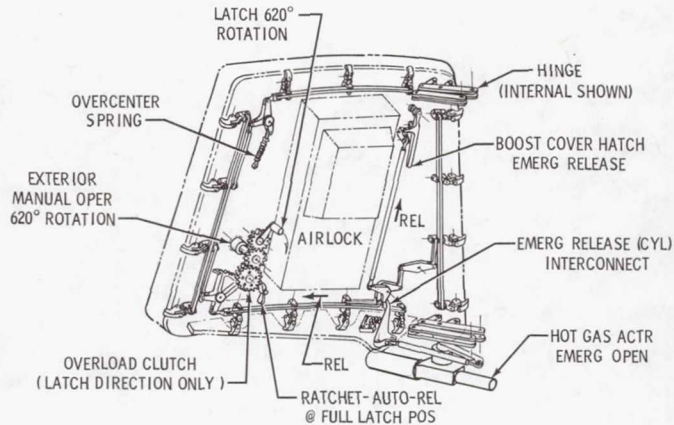
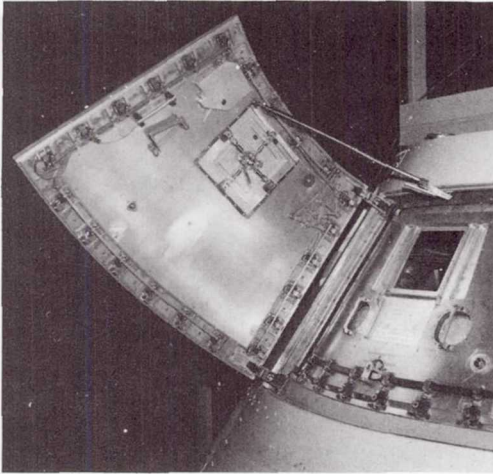
Not withstanding this emphasis on the potential problems created by combustibles in the spacecraft, it can be seen in retrospect that attention was principally directed to individual testing of the material. What was not fully understood by either North American or NASA was the importance of considering the fire potential of combustibles in a system of all materials taken together in the position which they would occupy in the spacecraft and in the environment of the spacecraft.²⁶

Leland Atwood and Dale Myers used charts to emphasize to Congress the changes that the company intended to make in both construction and test operations. North American would assign a spacecraft manager and a personalized team to each vehicle, appoint an assistant program manager whose only concern was safety, place additional controls on changes made during modification and checkout phases, and assign personal responsibility to specific inspectors. The company would also revise its fabrication and inspection criteria; expand its quality standards, issuing a handbook with better visual aids; install more protected wiring and plumbing; and insist upon additional major inspections. Myers then discussed fire-related hardware changes: the new unified hatch, materials reevaluation, fluids and plumbing reassessment, electrical system improvements, revised on-the-pad operations, and flammability tests.²⁷

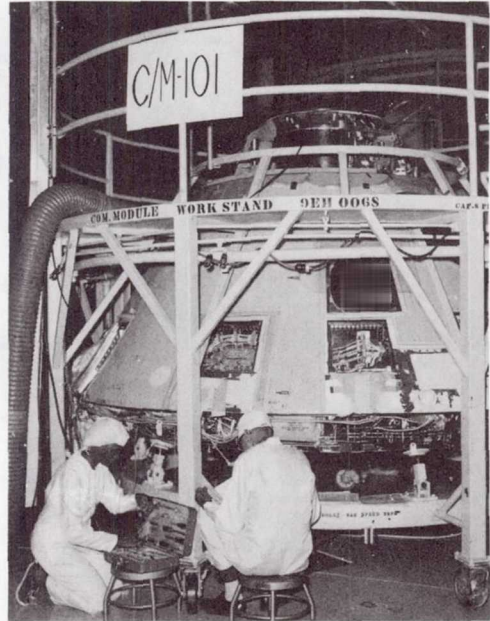
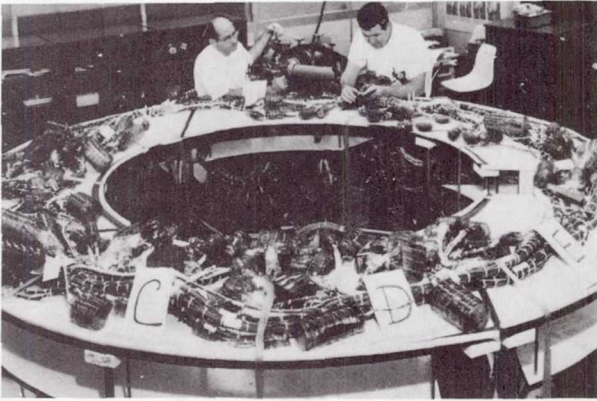
In Houston, Faget's engineering and development activity ran all sorts of tests on materials and components, and Robert Gilruth sent Borman with a Houston "tiger team" to Downey in mid-April.* The astronaut was to make on-the-spot decisions on contractual changes for the unified hatch, better wiring and plumbing techniques, and other improvements that had been planned even before the accident. Borman's tiger team watched closely, lending its assistance when necessary, as North American engineers went over the spacecraft piece by piece.²⁸

What had happened to the command module, obviously, could just as well happen to the lunar module. Immediately after the fire, Thomas J. Kelly and a host of Grumman workers began a comprehensive review of materials in the lunar lander. Low sent Robert L. Johnston, a materials expert, to help Kelly's group. Grumman replaced nylon cloth in the spacecraft, relying mostly on Beta fiber (an inorganic substance developed by the

* Members of the tiger team were Douglas Broome, Aaron Cohen, Jerry W. Craig, Richard E. Lindeman, and Scott H. Simpkinson.



The command module's two-hatch system (above left) was replaced by the single crew hatch, with emergency features as shown in the drawing. At left below, the CM wiring harness goes through x-ray inspection. In the stand at North American, an electrical installer for CM-101—now scheduled for the first manned Apollo flight—carefully replaces tools in an accountability kit. (A wrench had been found embedded in the electrical wiring of CM-012, when it was taken apart after the fire.)



Corning Glass Works, that would not catch fire nor produce toxic fumes). Perhaps the most important application of this material was as “booties” around circuit breakers, to lessen the possibilities of electrical shorts. In other areas, Grumman worked on its forward hatch, to ensure a crew exit within 10 seconds; the environmental control system; and a cabin and ex-

terior pressure equalization system. All in all, the changes would add a three-to four-month delay in deliveries to the schedule trouble the lander was in even before the fire. Phillips sent a group headed by Roderick O. Middleton of Kennedy to look into Grumman's quality control and inspection procedures. Middleton's audit team completed its report in mid-May, giving Grumman generally good marks in the manufacturing process.²⁹

In Washington, on 9 May, Webb was again called on the carpet by the Senate committee. The Phillips report was again a major subject for debate, this time in a context that made it appear that the NASA-North American relationship was in danger of becoming a political football. The very next day, however, congressional questioning began to wind down. As Congressman John W. Wydler put it:

Essentially the story of the Apollo accident is known to the American people. We have admissions and statements about the things that NASA . . . and . . . North American Aviation [were] doing wrong. . . . But I want to say this to you, Mr. Webb. Over the past few years . . . I probably have been one of the most critical members on this committee of NASA. . . . It appeared to me . . . that you have had it too easy for your own good from this committee. This is not a criticism being directed at you or the Space Agency, but a criticism being directed inwardly at the Congress and this committee. I feel right now that you got less criticism than you deserved [in the past, but now] you are getting more criticism than you deserve. I don't intend to add to it for that reason.

Wydler did not really stop there, of course, but the investigation did begin to fade away. NASA and North American began implementing the technical recommendations. To some degree, the accident actually bought time for some pieces of Apollo—the lunar module, the Saturn V, the guidance and navigation system, the computers, and the mission simulators—to catch up with and become adapted to the total configuration.³⁰

Meanwhile, on 23 April 1967 the Soviet Union announced the launching of Vladimir M. Komarov aboard a new spacecraft. *Soyuz I* appeared to be functioning normally at first. On its second day of flight, however, the craft began to tumble, and Komarov had to use more attitude fuel than he wanted to get the ship under control. He tried to land during his 17th circuit but could not get the proper orientation for retrofire. Komarov succeeded in reentering on the 18th revolution, but his parachute shroud lines entangled. The cosmonaut was killed on impact. So both *Soyuz I* and Apollo 1 put their programs through traumatic reassessments. No one found any consolation in a "rebalanced" space race. In fact, Webb took the occasion to emphasize the need for international cooperation by asking: "Could the lives already lost have been saved if we had known each other's hopes, aspirations and plans? Or could they have been saved if full cooperation had been the order of the day?"³¹

CHARIOTS FOR APOLLO

THE SLOW RECOVERY

Within days after the Thompson Board's report, more than a thousand of those at the Manned Spacecraft Center who were working directly in support of the formal investigation began making suggestions for meeting the board's recommendations. Materials selection, substitution, and stowage inside the command module were thoroughly restudied; and all cloth parts made of nylon were replaced by Beta fiber, teflon, or fiber glass. These substitutes were chosen after more than 3000 laboratory tests had been run on more than 500 different kinds of materials.³²

Of immediate importance was the new unified hatch—unified meaning that the complicated two-hatch system was redesigned into a single hatch. The new component was heavier than the old, but it would open outward in five seconds, had a manual release for either internal or external operation, and would force the boost cover cap out of the way on opening. It could also be opened independently of internal overpressure and would be protected against accidental opening by a mechanism and seal similar to those used on Gemini.

The management of all industrial safety offices within NASA was revamped, with responsibilities flowing directly to the top at each location. At the launch center, fire and safety precautions were upgraded and personnel emergency preparations were emphasized as never before. Also, at the launch complex itself, a sliding wire was added to the service structure to permit a rapid descent to the ground. Reliability and test procedures were more firmly controlled, making it difficult to inject any last minute or unnecessary changes.

At the Manned Spacecraft Center, full-scale flammability testing continued, first to try to duplicate the conditions present on 27 January and then to find ways to improve the cabin atmosphere and the environmental control system. The tests led to replacing all aluminum oxygen lines that had solder joints with stainless steel tubing that used brazed joints. Aluminum tubing solder joints that could not be eliminated from the coolant system were armored with sleeves and seals wherever exposed. NASA decided to keep the water-glycol coolant fluid (covering it with flame resistant outer insulation) and added emergency oxygen masks for protection from smoke and fumes.³³

At NASA Headquarters, Webb directed Mueller to revamp and reorganize the major supporting and integrating contractors to put more pressure on North American, as well as on those manufacturing the other Apollo vehicles. Boeing was given a technical integration and evaluation contract, to act as a watch dog for NASA; and General Electric was told to assume a much greater role in systems analysis and ground support.³⁴

The contract situation with North American had reached a peculiar stage even before the fire. The cost-plus-incentive-fee contract NASA had

negotiated with North American in October 1965 had expired on 3 December 1966. In late January 1967, the legal status of relations was in some doubt. The objectives of the incentive contract had been to reverse the trend of continuing schedule slips, to get Block I vehicles delivered from the factory, to speed up Block II manufacturing, and to bring costs under control. Progress had been made on all fronts by the end of 1966; the flights of Block I spacecraft 002, 009, and 011 had been 80 percent successful, Block II work had moved along, and the cost spiral had stopped.

Despite the fire, John J. McClintock, chief of the Apollo office program control division, advocated in April 1967 that NASA negotiate a follow-on incentive contract, placing heaviest emphasis on flight performance and quality and less on schedules. North American's business negotiators had already conceded that no incentive fee could be expected for spacecraft 012. The closeout cost for the Block I series was set at \$37.4 million. This meant that the learning phase of Apollo had cost \$616 million. Furthermore, North American agreed that there would be no charge for changes resulting from the AS-204 accident—such as the wire harnesses, environmental control system improvements, and the unified hatch. Changes that would enhance mission success or operational flexibility—changes in the reaction control system, revised inspection criteria, or features to increase mission longevity—would cost money.³⁵

After the uncertain days of February, NASA officials began to sense that a recovery from the tragedy was under way. Drawing together, workers at all NASA centers, representing a vast amount of technical strength, recovered their morale through hard work more rapidly than might have been expected. Much of Apollo's chance for recovery rested on the fact that the Block II advanced version of the command module was well along in manufacturing and that most of its features were direct improvements over the faults of the earth-orbital Block I. Moreover, the Saturn V, after experiencing difficulties in the development of its stages, seemed on the track now.

By early May, Webb and his top staff were looking for ways to show Congress that Apollo was on the road to recovery. Mueller proposed flying a Saturn V as soon as possible. Phillips stressed the building and delivery of standard vehicles. Any modifications of support missions other than the lunar landing (such as Apollo Applications) should, he and Mueller agreed, be entirely separate from the mainstream of Apollo. Moreover, the science program in Apollo should be carried strictly as supercargo.³⁶

At the time of the accident, the flight schedule had listed a possible lunar landing before the end of 1968. After the impounding of material evidence and the halting of oxygen chamber testing until the investigation was over, that Apollo schedule was obviously no longer valid. Several weeks after the fire Seamans told Mueller to scrap all official flight schedules for manned Apollo missions, using only an internal working schedule to prevent

CHARIOTS FOR APOLLO

avoidable slips and cost overruns. By March, Mueller had told Seamans that NASA could commit a Saturn V to a mission. In June Low said he believed that the spacecraft had turned the corner toward recovery, since the changes related to the fire had been identified and were being made. Even if everything went perfectly, however, more than 14 months would be needed for complete recovery.* ³⁷

To make certain of stronger program control in the future, Low decided that all proposals for changes would have to pass an exceedingly tough configuration control board before being adopted. He asked George W. S. Abbey, his technical assistant, to draft a strongly worded charter for the control board. Low next announced that he, Faget, Chris Kraft, Slayton, Kenneth Kleinknecht, William Lee, Thomas Markley, and Abbey (as secretary) would meet for several hours every Friday. When medical and scientific affairs were on the agenda, Berry and Wilmot N. Hess would join the group. Low himself would make all final decisions, and his new board members had the authority to ensure that his decisions were carried out.³⁸

If Apollo had seemed complicated before the fire, it appeared even more so afterward. If it gave an impression of being hurried in late 1966, it gathered still more momentum in late 1967. If an extreme level of attention had been given to aspects of crew safety and mission success before the deaths of Grissom and his crew, it rose yet higher after they were gone. But among the Apollo managers there were still nagging fears that something might slip past them, something might be impossible to solve. By mid-1967, however, they were so deep in their work that they could not avoid a growing confidence.

Atwood said the biggest mistake had been locking the crew inside the spacecraft and pumping in oxygen at a higher than sea-level pressure. There was no way to eliminate fire hazards under such conditions. So NASA and North American substituted a nitrogen-and-oxygen atmosphere at ground level, replacing the nitrogen gradually with pure oxygen after launch. Bergen, who had taken over the leadership of North American's Downey division from Storms, moved into the factory while recovery work was going on. He made a practice of appearing on the plant floor, walking around asking questions, during each of the three shifts. Some of the workers wondered if he ever slept. During visits to Downey, Low was often to be seen watching plant activities on Saturdays. Many doubted, Bergen later said, that the recovery could be made in a reasonable time because "everything had come to

* During fiscal 1970 budget hearings before the House space committee, Congressman James Fulton asked George Mueller on 11 March 1969 to give a "statement in the record of the actual cost in dollars . . . and actual delay caused . . . by the Apollo 204 fire. . . ." Mueller's submitted reply said, "The estimated additional direct cost to Apollo . . . resulting from the Apollo 204 accident is \$410 million, principally in the area of modifications to the spacecraft. The accident delayed the first manned flight test of the Apollo spacecraft by approximately 18 months."

a screeching halt." Bergen credited Gilruth's assignment of Borman and his group and Healey's performance as manager of spacecraft 101 as the keys to getting the command module back into line.³⁹

NASA's leaders, after reviewing the progress, decided that it was time for a flight demonstration to prove that the bits and pieces of Apollo had been picked up and were being put back together. Apollo-Saturn Mission 501, with command module 017, was set for early autumn of 1967. If the first flight of the Apollo-Saturn V combination was successful, the rest would follow in due course.⁴⁰

As early as 9 May 1967, Houston proposed four manned missions—one with only the command and service modules, the other three with all the vehicles—before any attempt at a lunar landing. Headquarters in Washington believed that the lunar-landing mission might be possible on the fourth manned flight, which Houston thought was unrealistic—"all-up" should not mean "all-out." Kraft warned Low that a lunar landing should not be attempted "on the first flight which leaves the earth's gravitational field":

There is much to be gained from the operations which could be conducted on the way to and in the vicinity of the moon. The many questions of thermal control away from the earth's environment, navigation and control during translunar flight, communications and tracking at lunar distances, lighting conditions and other flight experiences affecting astronaut activities in the vicinity of the moon, lunar orbit and rendezvous techniques, the capability of the MSFN to provide back-up information and many other operating problems will be revealed when we fly in this new environment. It would be highly desirable to have had this experience when we are ready to commit to a lunar landing operation, thereby allowing a more reasonable concentration on the then new problems associated with the descent to the lunar surface.⁴¹

Deputy Administrator Seamans and his aides made a swing around the manned space flight circuit in June, visiting Kennedy, Huntsville, Mississippi Test, Michoud, and Houston. In the course of the tour, Seamans observed a definite upsurge of confidence within the Apollo team, although there were still worries. For example, at Kennedy, with planning predicated on a six-week checkout of the Apollo-Saturn in the Cape facilities and launch during the seventh week, there was some feeling that the schedule for the launch of Apollo 4* was extremely tight. Huntsville was still worried about

* Grissom's crew had received approval for an "Apollo 1" patch in June 1966, but as the time for the launch approached NASA Headquarters was leaning toward calling that mission "AS-204." After the accident, the widows asked that Apollo 1 be reserved for the flight their husbands would never make. Webb, Seamans, and Mueller agreed. For a time, mission planners in Houston called the next scheduled launch "Apollo 2." In March 1967, Low wrote to Mueller, suggesting that, for historic purposes, the flights should be called "Apollo 1" (AS-204), "Apollo 1A" (AS-201), "Apollo 2" (AS-202), and "Apollo 3" (AS-203). In April, Julian Scheer, Assistant

CHARIOTS FOR APOLLO

the S-II stage of the launch vehicle, which had gone through a rather tough year of testing in 1966. And Houston, as a result of fire-related changes, was fighting the age-old problem of fattening spacecraft. On top of this, the lunar module was still having ascent engine instability problems, also left over from the preceding year.⁴²

The next month, in July, Mueller and an entourage visited the North American plant at Downey* to see what the contractor had done about the Thompson Board's recommendations. As they walked around the manufacturing area, Mueller seemed generally pleased with progress.⁴³ Within a very few months, that progress was to be demonstrated in a very satisfactory manner.

Apollo 4 AND SATURN V

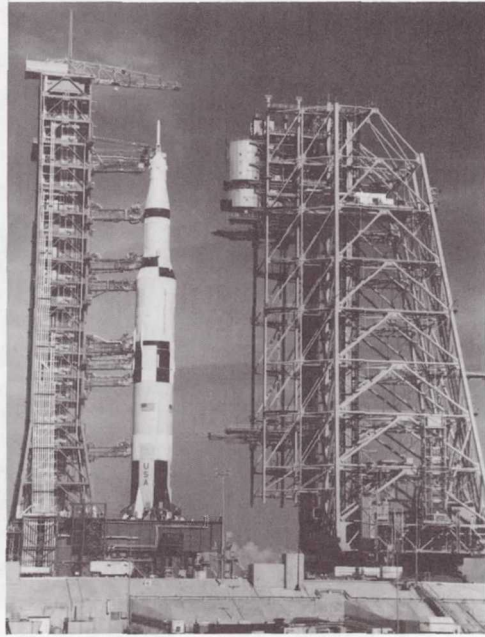
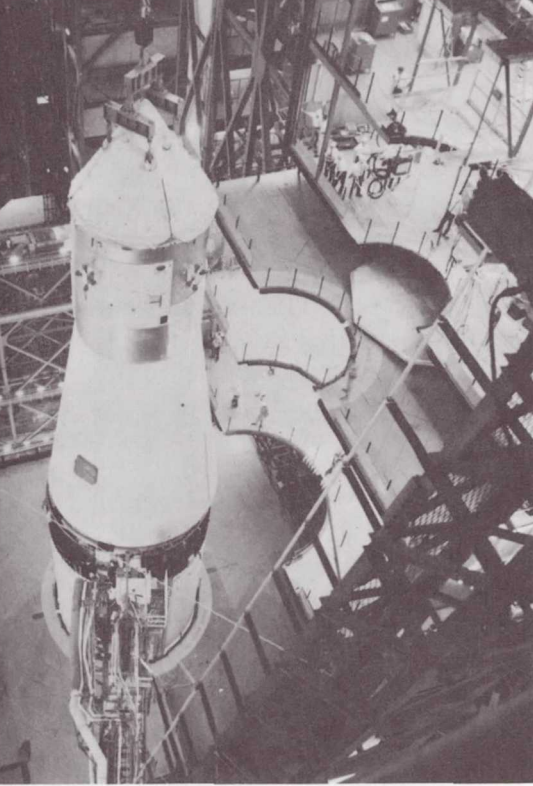
Birds, reptiles, and animals of higher and lower order that gathered at the Florida Wildlife Game Refuge (also known by the aliases of Merritt Island Launch Annex and Kennedy Space Center) at 7:00 in the morning of 9 November 1967 received a tremendous jolt. When the five engines in the first stage of the Saturn V ignited, there was a man-made earthquake and shockwave. As someone later remarked, the question was not whether the Saturn V had risen, but whether Florida had sunk.

Apollo-Saturn mission 501, now officially *Apollo 4*—the first all-up test of the three-stage Saturn V—was on its way. On its top rested spacecraft 017, a Block I model with many Block II features, such as an improved heat-shield and a new hatch. The aim of the mission, in addition to testing the structural integrity and compatibility of the spacecraft-launch vehicle combination, was to boost the command and service modules into an elliptical orbit and then power-dive the command module (in an area over Hawaii) into the atmosphere as though it were returning from the moon to the earth. *Apollo 4* also carried a mockup of the lunar module. Weighing more than 2.7 million kilograms when fully fueled with liquid oxygen and a kerosene mixture called RP-1, the Saturn V first stage generated 7.5 million pounds of thrust at liftoff.⁴⁴

The flight went almost exactly as planned, and the huge booster rammed its payload into a parking orbit 185 kilometers above the earth.

Administrator for Public Affairs, notified the centers that the NASA Project Designation Committee had approved the Office of Manned Space Flight recommendation of "Apollo 4" for the first Apollo-Saturn V mission (AS-501), but there would be no retroactive renaming of AS-201, -202, or -203. Much correspondence followed, but the sequence of, and reasoning behind, mission designations has never been really clear to anyone.

* In May, North American's Space and Information Systems Division in Downey had been renamed simply the "Space" Division, to reflect its major mission.



Apollo 4: Command module 017 and Saturn 501 are assembled in the Vehicle Assembly Building, Kennedy Space Center, at left. The spacecraft stack at Launch Complex 39 (right) is poised for the first Saturn V mission and first use of LC 39. The umbilical tower on the launch pad to the left of the spacecraft feeds fuel and electricity to the launch vehicle-spacecraft combination. The mobile service structure to the right may be moved to enclose the spacecraft with an office-workshop compartment and other work levels.

After two revolutions, the S-IVB third stage propelled the spacecraft outward to more than 17 000 kilometers, where it cut loose from the S-IVB and started falling earthward. Then the service module fired, to send the spacecraft out to 18 000 kilometers for a four-and-a-half-hour soak in the super-cold and hot radiation of space. Telemetry signals noted no degradation in cabin environment. With the spacecraft nose pointed toward the earth, the service module engine fired again. When the spacecraft reached the 122 000-meter atmospheric reentry zone, it was blunt-end forward and traveling at a speed of 40 000 kilometers per hour.

Seamen on the U.S.S. *Bennington*, the prime recovery ship in the Pacific, watched the descending spacecraft, with its parachutes in full bloom, until it landed 16 kilometers away about nine hours after its launch from Florida. Swimmers jumped from helicopters to assist in the recovery of spacecraft 017, which took about two hours. Technically, managerially, and psychologically, *Apollo 4* was an important and successful mission, especially

CHARIOTS FOR APOLLO

in view of the number of firsts it tackled. It was the first flight of the first and second stages of the Saturn V (the S-IVB stage had flown on the Saturn IB launch vehicles), the first launch of the complete Saturn V, the first restart of the S-IVB in orbital flight, the first liftoff from Complex 39, the first flight test of the Block II command module heatshield, the first flight of even a simulated lunar module, and so on. The fact that everything worked so well and with so little trouble gave NASA a confident feeling, as Phillips phrased it, that "Apollo [was] on the way to the moon."⁴⁵

Even before spacecraft 017 had set out on its trip, the Manned Spacecraft Center was working hard on how to get Apollo to the moon before 1970—only a little more than two years away. On 20 September, Low and others met with top manned space flight officials in Washington to present the center's plan, the key features of which were the need for additional lander and Saturn V development flights and the incorporation of a lunar orbital flight into the schedule. Owen Maynard presented plans for scheduling seven types of missions that would lead step by step to the ultimate goal. He described these steps, "A" through "G," with G as the lunar landing mission.

Phillips asked that the group consider carefully both the pros and cons of flying an additional Saturn V flight. Wernher von Braun and Low favored the flight—von Braun, because he felt the launch operations people would need the experience, and Low, because he believed that data from several flights would be needed to make certain that the big booster was indeed ready for its flight to the moon. Against these opinions, Phillips cited the tremendous workload an added flight would place on the preflight crews at Kennedy, and Mueller reminded the meeting of the already crowded launch schedule for 1968. An additional lunar module mission would be flown only if LM-1 were unsuccessful.

Most discussion centered on the insertion of a lunar orbital flight into the schedule. Houston wanted "to evaluate the deep space environment and to develop procedures for the entire lunar landing mission short of LM descent, ascent and surface operations." Mueller remarked that he regarded the lunar orbit mission as just as hazardous as the landing mission. But the Texas group argued that they had no intention of flying the vehicle closer to the moon than 15 000 meters. They pointed out that the crew would not have to train for the actual landing, but it would give them a chance to develop the procedures for getting into lunar orbit and undocking and for the rendezvous that the lunar landing crew would need. Mueller said, "Apollo should not go to the moon to develop procedures." Low reminded him that crew operations would not be the main reason for the trip; there was still a lot to be learned about communications, navigation, and thermal control in the deep space environment.⁴⁶ Although a final decision on the lunar orbital mission was not made until later, Maynard's seven-step plan was generally adopted throughout NASA.

TRAGEDY AND RECOVERY

Basic Missions

Mission	Mission Number	Objective	Launch Vehicle	Trajectory	Duration
A	4 & 6	Launch vehicle, spacecraft development, lunar-return entry velocity	Saturn V	16 600-kilo-meter apogee	About 8.5 hours
B	5	Lunar module development, propulsion and staging	Saturn IB	Low elliptic orbit	About 6 hours
C	*	Command and service module evaluation/crew performance	Saturn IB	Low earth orbit	Up to 11 days
D	*	Lunar module evaluation/command and service modules/crew performance combined operations	Saturn V or dual IB	Low earth orbit	Up to 11 days
E	*	Command and service modules/lunar module combined operations	Saturn V	High earth orbit	Up to 11 days
F	*	Lunar mission/deep space evaluation	Saturn V	Lunar orbit	Up to 11 days
G		Lunar landing			

* Mission number dependent on success in steps A and B.

Plenty of wrinkles remained to be ironed out, but by the end of 1967 Apollo seemed to be rounding the corner toward its ultimate goal, despite the most tragic event that manned space flight had so far encountered.

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10

Race with the Decade

1968: First Half

NASA officials faced 1968 with some satisfaction and a little trepidation. *Apollo 4* the previous November had been a triumph, but the Apollo team might have to do just as well six times in 1968 and five in 1969. That string of successes seemed to be a necessary prelude to a timely lunar landing.¹ Against this backdrop of mounting schedule pressures, a spate of technical problems cropped up. The most worrisome were those connected with the lunar module. It had grown too fat again and still had problems with metal cracking and with the ascent engine during test firings. Combined, these faults played havoc with delivery schedules and posed a definite threat to achieving Apollo's mission within the decade.

The command module also had some unresolved worries, although North American had made good progress in its redefinition and qualification. Flammability testing and the question of cabin atmosphere on the pad and at launch carried over into the new year, as did the difficulties in getting systems to the spacecraft production line at Downey.²

WORRIES AND WATCHDOGS

Tardy deliveries by subcontractors were among the bigger stumbling blocks that North American faced in putting the command and service modules together. Eberhard Rees, an expert in manufacturing management from Marshall Space Flight Center, was lent to George Low, Apollo program

CHARIOTS FOR APOLLO

manager at the Manned Spacecraft Center, to solve fabrication problems. In the later months of 1967, Rees visited North American and soon realized that cooperation between the prime contractor and the subsystem suppliers was not close enough. North American engineers, he said, should spend more time at the subcontractors' plants while subsystem assemblies were in critical stages of fabrication. He also recommended that North American borrow some inspectors from General Electric to help conduct vendor surveys, specification reviews, and test failure assessments.³

The subsystem situation came to the attention of George Mueller, Associate Administrator for Manned Space Flight at Headquarters, when he visited Downey late in 1967. Mueller on his return to Washington asked Edgar M. Cortright, his deputy, to go to the major companies, review the status of hardware, and see if the condition could be improved.⁴

During January and February 1968, Cortright traveled to nine Apollo subcontractors. He was impressed with people, equipment, and facilities but not at all pleased with hardware or schedules. Cortright found that neither North American nor Grumman knew enough about the status of their subcontractors' work to be able to forecast deliveries with any degree of accuracy. The subcontractors, Cortright also said, should be more aware of the importance of their systems in the total program—they should not just deliver their products to the dock in Downey or Bethpage and walk away. He was upset about failures in electronic parts, especially when he found that the subcontractors were doing their best to solve their problems by themselves by trial and error. Low asked the Houston subsystem managers to look into these deficiencies and correct them.⁵

Just the barest hint of something wrong with electrical parts, anything that might be a fire hazard, captured the immediate attention of special guardian groups. Spacecraft wiring and materials, cabin atmospheres, and crew safety were the subjects of many meetings. Third-party groups, such as a Senior Flammability Board, a Materials Selection Review Board, and a Crew Safety Review Board, were set up to ensure extra safeguards.

Late in 1967, Houston Director Robert Gilruth led a contingent of NASA officials to a meeting with William Bergen and his staff at North American* to discuss flammability problems of the coaxial cable in the command module. Under particular scrutiny was spacecraft 101, slated for the first manned Apollo mission. After visually inspecting the vehicle and watching motion picture films of tests, the group concluded that 23 meters of the coaxial cable might be flammable. There were several options on what to

* On 22 September 1967, North American Aviation and the Rockwell-Standard Corporation had merged into a single company, North American Rockwell Corporation, which was then divided into two major elements—the Commercial Products Group and the Aerospace and Systems Group. For consistency and brevity, this history will refer to the latter as "North American."

do about it—replace it, wrap it with aluminum tape, partially wrap it to provide fire breaks, or leave it alone. Since other spacecraft wiring and electrical equipment might be damaged during replacement, even with extreme care, they decided it would be safer to fly 101 essentially as it was, with the exception of one bundle that would be wrapped.*⁶

No sooner had one NASA group acted than another demanded a defense of what had been done. Aleck C. Bond, speaking for the Houston Materials Selection Review Board, queried Low about the cable. Low pointed out that the decision had been made at the highest Apollo management level of both North American and NASA. He also reminded Bond that, in the NASA system of checks and balances, the board did not approve changes. It only recommended approval or disapproval. Low then required that all deviations be assessed by his Configuration Control Board and forwarded to Apollo Program Manager Phillips in Washington for final review.⁷

Most of the Flammability Board's attention focused on cabin atmosphere at the launch site, which also affected materials selection. Established in September 1967, with Gilruth as chairman, the board directed several series of tests under a variety of atmospheric mixtures and pressures for pad operations. Thirty-eight tests had been completed by 7 January 1968. In the middle of the month, a second series began, using principally a 60-percent-oxygen and 40-percent-nitrogen mix (normal atmosphere is 21 percent oxygen and 78 percent nitrogen, with traces of other gases). This series ended on 25 January, and evaluations began.

Max Faget, whose engineers in Houston ran many tests for Gilruth's board, said they used pure oxygen at a higher than normal pressure on the pad to check for air leaks from the cabin. After the Apollo 204 fire, everyone was aware that this was dangerous. They then ran pure oxygen tests at one-third the pressure (which simulated orbital conditions). With cabin fans off and no other means of spreading the flames, they found that fire would not propagate as rapidly in space. So Faget's group agreed that if they could make the spacecraft safe on the ground, it would be safe during flight.

But there was no way to put 100-percent-fireproof materials in the spacecraft, especially in the electrical system. Many persons began campaigning for a two-gas atmosphere, with a higher concentration of nitrogen than oxygen. Use of this mixture would have required completely rebuilding the spacecraft to withstand the pressures of a sea-level atmosphere. The command module could withstand only about half that pressure in space, and the lunar module even less. Moreover, a mixed atmosphere in space would complicate the environmental system—Faget said the system "would get confused and would put too much nitrogen in the cabin, a very insidious thing

* Since they were not as far down the production line as 101, spacecraft 103 through 106 would have their coaxial cables removed and wrapped, which should not take longer than five days. Later spacecraft would be fitted with coaxial cables that met nonmetallic materials guidelines.

CHARIOTS FOR APOLLO

because there was no way to detect [it]." The astronauts would just get sleepy—and die. Another complication was that a switch back and forth from the two-gas system in the cabin and the 100 percent oxygen in the hoses connected to the suits might give the crew aeroembolism, or the bends.

So the question was twofold: How much nitrogen was needed on the pad to prevent fire? And how much oxygen was needed during launch while the cabin pressure relief valve was venting? Tests revealed that a 60-percent-oxygen and 40-percent-nitrogen mixture at a pressure of 11.2 newtons per square centimeter (16.2 pounds per square inch) on the pad would result in 1.4 newtons (2 psi) in orbit after venting, which would give a partial pressure of oxygen compatible with the oxygen atmosphere and pressure in the suits. The cabin pressure would be lower at first, but the mixture would be breathable and it would sustain life. In fact, by the time the craft reached orbit, Faget said, the cabin mixture would actually be about 80 percent oxygen. And there was a bonus in this arrangement beyond the safety factor: no structural changes were needed in the spacecraft to accommodate this combination of oxygen and nitrogen.⁸

Low promised Phillips a decision on the prelaunch atmosphere in time for spacecraft 101's Design Certification Review. A third set of tests, using boilerplate 1224, confirmed conclusions drawn from the second series. Gilruth's Flammability Board met on 4 March and recommended the 60/40 mixture for the launch pad. On 7 March, Mueller's Certification Board accepted this recommendation. In April, NASA's medical group, expressed "enthusiastic approval of the . . . decision to adopt the 60/40 atmosphere."⁹

For a while there was a good deal of discussion about the lunar module cabin atmosphere on the launch pad. Low recommended 100 percent oxygen for the LM, since there was no crew and little electrical power in the vehicle during launch. Moreover, the spacecraft-lunar module adapter, which held the lander, was filled with nitrogen, reducing flammability hazards to almost nothing. This procedure, Low pointed out, would save some of the lander's oxygen supply, as well as minimizing crew procedures in changing the mixture to pure oxygen after launch. Marshall, however, objected, because any oxygen escaping from the lander during the launch phase might come in contact with hydrogen leaking from the S-IVB into the adapter and start a fire. Houston conceded that the advantages of launching the lunar module with pure oxygen had to give way to Huntsville's concerns; the atmosphere in the lander's cabin at launch would not exceed 20 percent oxygen.¹⁰

Another set of watchdogs, formed to consider manned operation of the machines, was the Apollo Crew Safety Review Board. Since Gilruth's team was investigating "spacecraft fire safety and air-on-the-pad," the new group, at its first meeting in March 1968, began looking for problems that might be missed by other specialized committees. Led by John Hodge in Houston, the board concentrated on operations—all activities from the time the crew boarded the spacecraft through the launch phase—searching for weak links

and hazards. One big worry that had to be faced was the possibility of a Saturn engine shutting down on the pad or during the launch trajectory.¹¹

The Hodge Board was not the only group worrying about a Saturn V engine malfunction. Major General David M. Jones, Commander of the Eastern Test Range, reminded KSC Director Kurt Debus that the launch vehicle would remain over the Cape area for almost two minutes. Jones wanted the vehicle to move out over water as quickly as possible. Debus told Phillips what Jones had asked, adding that the launch azimuth should not be tampered with, since a wide range would be needed for a lunar launch. Phillips turned to Marshall for an answer, and the launch vehicle engineers modified the pitch program so the vehicle would head eastward sooner after launch than originally planned.¹²

Although the Saturn V may have been the key vehicle for escaping the earth's gravity for the lunar trip, the keystone in the arch leading to the surface of the moon itself was the lunar module. At least, that was the way the Flight Operations Division in Houston viewed LM-1's upcoming trial in earth orbit.¹³ And the path to the launch pad for that craft had been a long and arduous one.

Apollo 5: THE LUNAR MODULE'S DEBUT

A 1966 schedule called for LM-1 to be delivered to Cape Kennedy on 16 November of that year, but the craft ran into difficulties in manufacturing (see Chapter 8) and the months slipped by. Changes after the command module fire (see Chapter 9) caused further delays, and LM-1 did not arrive in Florida until 27 June 1967 (three months beyond its original launch date). John J. Williams, a veteran of both Mercury and Gemini, headed a 400-man spacecraft operations activity at Kennedy Space Center. When the spacecraft arrived, Williams' men made sure that it met specifications and then watched the contractor during test, maintenance, and modifications to see that systems and equipment worked.¹⁴

The launch vehicle for the LM-1 mission was the one that would have boosted the ill-fated Grissom crew into orbit. Saturn IB 204 had been at the Cape since August 1966. When it was taken down from Launch Complex 34 in March 1967, the launch preparation crew, under the direction of Rocco Petrone, inspected the booster for corrosion or any other damage it might have sustained during its long stay on the pad and then erected it on Launch Complex 37, getting it in place on 12 April.¹⁵

The Apollo stack for this mission was 55 meters high, but it looked stubby, since the launch escape tower and the command and service modules were missing. LM-1—legless, because it would burn up on reentry (it had no heatshield) and therefore needed no landing gear—rested inside the spacecraft—lunar module adapter.¹⁶

CHARIOTS FOR APOLLO

Twenty-five priorities, monitored by 17 specialists, would put the vehicle through its paces to make sure that it was safe for crew operations. Three items at the top of the list pertained to fire-in-the-hole (FITH) requirements, or tests to check structural effects, staging dynamics, and stability during a simulated lunar abort. (FITH simply meant firing the ascent stage engine while it was still attached to the descent stage.) Other objectives included operating the descent and ascent propulsion systems, starting and stopping each to simulate phases of the lunar landing mission.¹⁷

By late fall and early winter of 1967, most of the mission documents were ready. Mission Director William C. Schneider, who had played this same role in the Gemini program, issued the mission rules on 28 November, ladling out responsibilities and spelling out what would be done in almost every eventuality. As the final testing on the vehicles progressed toward launch, flight readiness reviews were held at the Cape and in Washington. In the first few days of the new year, Mueller wrote Administrator James Webb that the launch would take place "no earlier than" 18 January 1968.¹⁸

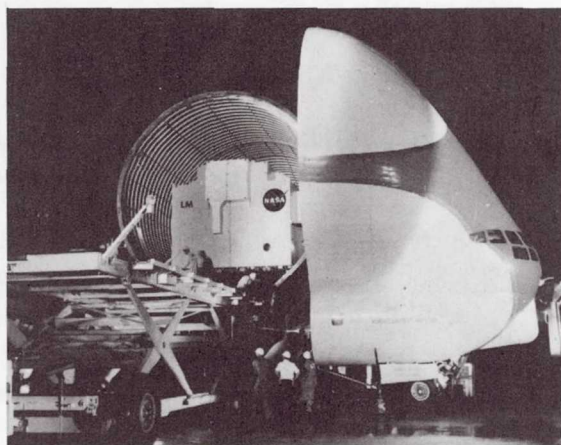
Rocco Petrone's launch team had difficulty loading the propellants, mainly because of procedural troubles, and small irritants such as clogged filters and ground support equipment problems further hampered the start of the mission. A simulated launch demonstration ended on 19 January, and the 22-hour countdown to launch began on 21 January. Back in Houston, lead flight director John Hodge and his chief assistant, Eugene F. Kranz, listened from the mission control center to the activities at the Cape launch center and waited patiently to take over direction of the flight once Apollo 5 cleared the pad.¹⁹

Just before dark, at 5:48 on the afternoon of 22 January, after several hours' delay because of equipment problems, *Apollo 5* lifted off. The powered phase of booster flight was uneventful, and LM-1, still attached to the S-IVB stage, went into orbit about 10 minutes into the flight. In less than 45 minutes, its attitude control engines pulled LM-1 away from the S-IVB. After checking out the spacecraft for two revolutions, ground control signaled the descent engine to fire for 38 seconds. Four seconds later, LM-1's guidance system sensed that the vehicle was not going fast enough and stopped the engine. The cutoff was a planned feature—in a manned flight, it would give the crew time to analyze the situation and decide whether the engine should be restarted to continue the mission. Under normal conditions, the burn would have started with full tank pressurization and would have reached the proper velocity within four seconds. For this mission, however, the tank was only partially pressurized and it would have taken six seconds to reach the required speed. Because of the premature cutoff, the flight controllers moved to a planned alternate mission.

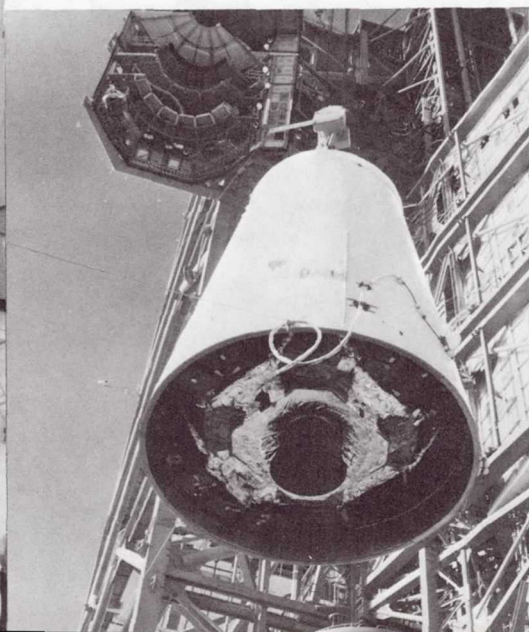
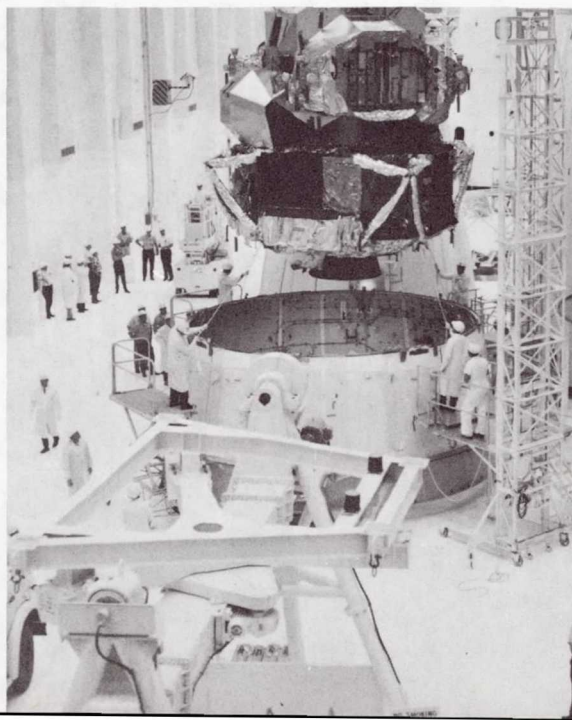
Ground control sent a switch-off signal to the guidance computer and cut in a mission programmer to command the lander's maneuvers. The descent engine was fired twice more (once for a full 33 seconds). There were



The Super Guppy Aero Spaceliner, billed as the "largest airplane in the world," delivered many space vehicles from factories to the Kennedy Space Center launch site. In late June 1967, the Super Guppy opened to deposit Lunar Module 1 at KSC in preparation for the Apollo 5 mission.



Ascent and descent stages, forming Lunar Module 1, are mated with the spacecraft-lunar module adapter in the Manned Spacecraft Operations Building at KSC (left below) in November 1967. Because its mission was earth-orbital flight, LM-1 had no landing gear. At right below, LM-1 inside the adapter is hoisted to the top of Saturn launch vehicle 204.



CHARIOTS FOR APOLLO

two ascent engine firings, one for the fire-in-the-hole abort maneuver. Mueller reported to Webb that all primary objectives had been achieved. LM-1 reentered the atmosphere, and its fiery remains plunged into the Pacific several hundred kilometers southwest of Guam on 12 February.²⁰

THE LM: SOME QUESTIONS, SOME ANSWERS

Following *Apollo 5*, it appeared likely that one of the six flights planned for 1968 might be canceled. Fewer flights should mean a better chance of landing a crew on the moon within the decade. After reading a preliminary version of the mission report, Phillips wired the three manned space flight centers not to plan a second unmanned lunar module mission. Shipment of LM-2 and its Saturn IB booster to the Cape was delayed, pending an assessment by George Mueller's Certification Board. On 6 and 7 March, the board agreed there was no reason for another unmanned lunar module flight. The first lunar module to carry men would be launched by a Saturn V later in 1968.²¹

The lander still had hurdles to clear, however, before anyone would be allowed to ride it in space. Ascent engine instability, for example, had been a matter of concern from August 1967 to June 1968. When Mueller and Phillips visited the builder of the engine in the summer of 1967, they agreed that Bell had a good chance of solving fuel-injector problems and getting a stable engine ready for the first manned lander. Nevertheless, NASA had hired Rocketdyne to develop an alternate injector, sending Cecil R. Gibson from the Houston center to work with Bill Wilson at Rocketdyne. This contract lasted for about a year, and Gibson and Wilson successfully stayed on schedule, held down costs, and got the job done.²²

One question that arose was whether a new and improved injector should be flown in a manned lander without a thorough revalidation test program. Joseph G. Thibodaux (Gibson's boss and chief of the Propulsion and Power Division in Houston, who had been asked to head a team to evaluate the injector) believed that it would be safe, so long as fuel did not enter the firing chamber before oxidizer. An Agena engine that had allowed the fuel to go first in the Gemini program had exploded during 1965.²³

Grumman and NASA officials met on 29 April to discuss the status of the injector. They were not happy with what they had discovered during visits to the subcontractor plants. Bell had been lax in configuration control, and Rocketdyne was having trouble getting engines to start and then to run smoothly. For some time, NASA Headquarters had considered asking Rocketdyne and Bell, even though they were competitors, to pool their knowledge to get the best possible injector. Rocketdyne might send its injector and some of its personnel to the Bell test cell for checkout. Al-

though hesitant at first, because this might slow down Bell's work, Houston told Grumman to coordinate this combined testing, calling on specialists from both subcontractors for help.²⁴

As time passed, Phillips and Low began to worry more and more about what would happen if the Rocketdyne injector were picked. How much testing would have to be done to make certain that a Rocketdyne engine was safe enough for a crew to fly on LM-3? And how long would it take?²⁵

Numerous trips were made to Bell by NASA officials, trying to get a grip on the problem. In May, after one visit, Low wrote: "If stability were the only criterion for acceptance, then a decision to select the Rocketdyne engine would have been clear. However, the Rocketdyne engine has also some short-comings, which are not yet completely understood." Low also believed that, if Rocketdyne were picked, it would take some "extraordinary efforts to integrate the new engine into the LM." That same month, a group led by Phillips of NASA and Joseph Gavin of Grumman met to discuss the alternatives they faced: (1) to use the Bell engine and Bell injector, (2) to ship Bell engines to Rocketdyne for fitting with Rocketdyne injectors, or (3) to send Rocketdyne injectors to Bell for installation in the Bell engine. Low finally decided to use a Bell engine and a Rocketdyne injector, with the entire assembly being put together and furnished by Rocketdyne.²⁶

At 17 and 19 June program reviews at Rocketdyne and Bell, respectively, Low learned that qualification tests were progressing with such excellent results (the engine had gone through 53 good tests) that an end to qualification by mid-August seemed possible.²⁷ Success now appeared certain, but the race with the decade was becoming very close.

Although the ascent engine was the most serious lander problem, there were others that created worries. For example, a window blew out of LM-5 during a test. On another occasion, a window fractured during a 72-hour high-temperature test. Corning Glass Works immediately began improving the panes, producing what Mueller called the strongest windows ever put in a spacecraft. And Grumman instigated a series of pressure tests to qualify the new windows.²⁸ All this took time.

Still another area that raised a red flag of concern was the discovery of stress corrosion cracks in the lander's aluminum structural members. This meant replacements and still more lost time, which angered George Mueller. He reminded Gilruth that these aluminum tubes (made of an alloy called "7075 T6") had caused problems in the past. Mueller could not understand why the cracks had not been noticed earlier. He wanted a "stress corrosion team" to find out why detection had failed and to figure out how to prevent a recurrence. Gilruth replied that there was no need for a special team. Stress corrosion surveys had been conducted in 1964, but the job simply "was not handled properly on the last go-round." Low then asked Joseph Kotanchik, a Houston structures expert, to investigate the overall

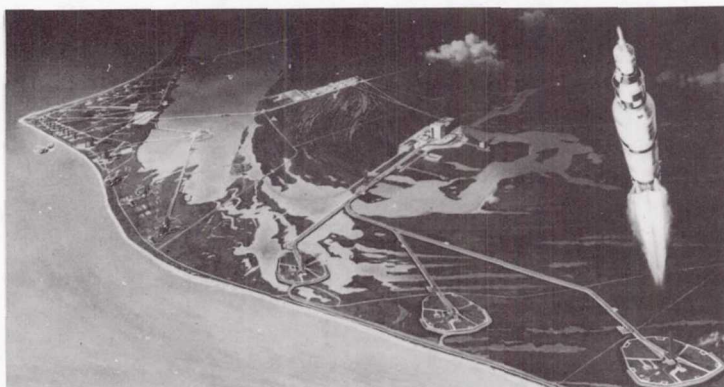
CHARIOTS FOR APOLLO

stress corrosion problem and to look into all equipment furnished by suppliers to the prime contractors to make sure no problems were lurking in any of these systems.²⁹

By mid-February 1968, Grumman had inspected six landers (LM-3 through LM-8), examining more than 1400 different components. Some parts were buried so deeply in the structure that they could not be reached. When no major cracks were found in the accessible areas, Grumman assumed that the problem was not as bad as NASA thought. Grumman did strengthen any parts not yet assembled by replacing the 7075 T6 tubes with 7075 T73, a heavier alloy. By the end of the month, Mueller told Webb he was no longer worried about stress corrosion.³⁰

Another nagging problem in the lander was broken wiring. Brigadier General Carroll H. Bolender, Manned Spacecraft Center's lunar module manager, received the impression when visiting the Cape that the wiring was in poor shape in LM-2 and not much better in LM-3. Bolender told his resident Apollo spacecraft representative at the Grumman plant in New York to emphasize to Grumman's engineering team the need to assist manufacturing in the wiring of the spacecraft. Some improvement came from this move, but not much. During an inspection of LM-3, several broken wires were discovered, apparently caused by carelessness during rework after testing. Toward the end of April 1968, fixtures were installed to protect vulnerable wire bundles and technicians were ordered to be more careful when working in the confined spacecraft areas, easing the problem to a certain extent. But the lander's schedule was getting tighter and tighter.³¹

Apollo's lunar missions were not launched from Cape Kennedy. Launch Complex 39, where Saturn Vs were launched, was on Kennedy Space Center grounds. (Launch Complexes 34 and 37 were on the Air Force Eastern Test Range, on the Cape itself.) Of the three launch areas planned for Complex 39 and shown in the 1965 drawing (the three right-hand areas below), the one at the extreme right, Area C, was not constructed; Areas (or Pads) A and B were built and used for all Saturn V launches.



And the vehicle was steadily getting fatter. Reductions were urged, but reducing diets in 1968 were nothing like those in 1965, when 1100 kilograms were shaved from the lander. NASA used the incentive contract as a lever to get Grumman moving on weight reduction, starting the second quarter of 1968 with the goal of cutting 22 kilograms off the ascent stage and 68 off the descent stage.³²

All in all, the chances for launching a manned lunar module during 1968 seemed very slim in June of that year. And Saturn V, the launcher, was still giving program officials some anxious moments.

Apollo 6: SATURN V'S SHAKY DRESS REHEARSAL

The success of *Apollo 4* gave good reason to believe that the Saturn V could be trusted to propel men into space. But NASA pushed on with its plans for a second unmanned booster flight, primarily to give the Pad 39 launch team another rehearsal before sending men into deep space on the Saturn V.

Getting Apollo 6 to the launch pad was a lengthy process. The S-IC first stage of the Saturn V arrived at Kennedy Space Center* on 13 March 1967. Four days later it was on a mobile launcher in the cavernous assembly building, awaiting the S-II second stage—which did not get to Kennedy until May. On 6 February 1968, a Tuesday morning, a crawler carrying the whole Apollo stack on its platform edged out of the building into a wind-driven rain and headed slowly down a track to the launch complex, five kilometers away. En route, trouble with communications circuits forced a two-hour wait. When communications were restored, the crawler resumed its snail's pace. At 5:00 that afternoon, the rain stopped, and the Apollo stack arrived at the launch area an hour later.³³

Although the spacecraft itself had no primary objectives to accomplish, a Block I version (CSM-020) with many Block II improvements (such as the new hatch) was allocated to the mission. Kleinknecht, the command and service modules manager in Houston, was pleased with the machine that North American sent to Kennedy, although he was upset when he learned that the protective Mylar film that covered the spacecraft during

* During Apollo 6 activities, a small intercenter irritation surfaced. Although almost everyone referred to the whole Florida launch layout as "the Cape," Albert Siepert, Deputy Director for Kennedy Space Center Management, wrote Wesley Hjornevik in Houston to point out that Launch Complex 39 was situated entirely within the geographical boundaries of the entity known as the "Kennedy Space Center, NASA." Noting that the widespread use of "the Cape" was a nostalgic hearkening back to Mercury and Cape Canaveral, Siepert nevertheless maintained that "NASA report writers ought not to confuse geographic proximity to the Cape as the same thing as being on it." However that may have been, the terminology "launched from the Cape . . ." continued to be used by the news media—and the present authors.

CHARIOTS FOR APOLLO

shipment was flammable. In engineering terms, it was a clean spacecraft. Only 23 engineering orders were outstanding (as opposed to the hundreds listed for spacecraft 012 only a year and a half earlier), and most of these were the kind that the spacecraft operations people at Kennedy normally handled anyway.³⁴ The spacecraft had no last-minute problems, but the mission planners did.

In November 1967, the idea of putting a camera in the window of the spacecraft to take some earth resources photographs had been explored in a review for Mueller at North American. John Mayer's MSC mission planners were hit hard by the late inclusion of the camera. Because Apollo 6 was unmanned, all the flight trajectory data had to be correlated with the photographic aims and a computer program had to be developed and fed into the onboard computer. After many careful checks, the mission planners decided that there might be a chance during the first orbit and part of the second to get some pictures of the area from Baja California to Texas.³⁵

Apollo 6 had been scheduled for the first quarter of 1968, but several brief postponements slipped it past that date. On 15 January, Mueller wrote Webb that the tank skirt of service module 008 had split during structural testing. The skirt on spacecraft 020 was strengthened to prevent a similar mishap. Then, after the stack had been trundled down the path to the launch area on a rainy day, water seepage was found in the Saturn's S-II stage, and some parts had to be replaced. And, finally, the countdown-to-launch practice did not end until 29 March.³⁶

At 7:00 a.m. on 4 April 1968, Saturn V 502 rose thunderously from its Florida launch pad to boost *Apollo 6* (AS-502) into orbit, but that was nearly the last normal thing the big rocket did. For the first two minutes, the five huge engines in the first stage roared, shook the ground, and belched fire evenly. Then there were thrust fluctuations that caused the vehicle to bounce like a giant pogo stick for about 30 seconds. Low-frequency modulations (known as the pogo effect) as high as ± 0.6 g were recorded in the command module, which exceeded design criteria (0.25 g was the upper limit permitted for manned flight in Gemini). Except for the bouncing and the loss of a piece of the panel in the adapter, the first stage did its job, however.

Very shortly after the second stage ignited, two of its five J-2 engines stopped. The other three engines had to fire longer to compensate for this loss of power. The second stage did not reach the desired altitude and velocity before its fuel gave out and it dropped away. To reach the required speed, the S-IVB third stage also had to burn longer than planned, putting the spacecraft into an orbit of 178 by 367 kilometers, instead of a 160-kilometer circular orbit.

Mission Director Schneider and Flight Director Clifford E. Charlesworth left the vehicles in a parking orbit for two circuits of the earth while system checks were performed, operational tests were conducted, and several

Mouth of the Colorado River and Gulf of California were photographed from the Apollo 6 spacecraft 220 kilometers above on 4 April 1968. Baja California is at the left, and the Mexican state of Sonora, showing the Sonoran Desert, is to the right of the river's mouth.



attitude maneuvers were carried out. Then flight control tried to restart the S-IVB, to simulate translunar injection, but the third stage refused to answer the call. The next step was to separate the command and service modules from the now useless S-IVB.

While *Apollo 6* had been whirling around the earth, the spacecraft's special 70-millimeter camera had been clicking away, getting some spectacular color stereo photographs.* These were later found to be excellent for cartographic, topographic, and geographic studies of continental areas, coastal regions, and shallow waters.

Following the system checks and the photography, controllers turned to an alternate mission. The service module engine was fired for 442 seconds,† which exceeded lunar mission requirements, to produce the simulated translunar injection maneuver. *Apollo 6* shot out to 22 200 kilometers. Although the spacecraft had enough altitude for a good simulation of an Apollo spacecraft returning to the earth from the moon, the service module engine no longer had sufficient fuel to give it the correct speed for its dive. The command module reached a velocity of 10 000 meters per second, about 1270 less than planned, and splashed down in the Pacific, missing its predicted impact point by 80 kilometers. The spacecraft was hauled aboard the U.S.S. *Okinawa* to complete its 10-hour mission.³⁷

* The camera photographed sections of the United States, the Atlantic Ocean, Africa, and the western Pacific Ocean. This camera had a haze-penetrating film and filter combination that provided better color balance and higher resolution than any photographs obtained during the Mercury and Gemini flights.

† If the S-IVB had made its second burn, the service module engine would have fired for only 280 seconds.

CHARIOTS FOR APOLLO

On 9 April 1968, a NASA news release declared that preliminary data on *Apollo 6* indicated that the spacecraft had done its job well. Mueller and Phillips, however, concluded that the overall flight had not been a success.

Apollo was not top international or even national news in April 1968, even though this flight was a major step in the program to land men on the moon. President Johnson had announced 31 March that he did not intend to seek reelection, hoping that this action would expedite the ending of the war in Southeast Asia. And on 4 April, the day of the flight, Martin Luther King, Jr., a civil rights leader of international stature, was assassinated in Memphis, Tennessee. About the only explaining that NASA had to do, therefore, was to the congressional committees on space activities, who seemed satisfied with what they heard.³⁸

But the Apollo team did not need a round of public criticism in April 1968. With the decade nearing its end, pressures were already exceedingly heavy. In the alphabet game of reaching the "G" (or lunar landing) mission, NASA had flown only two "A" missions (Saturn V unmanned) and one "B" (Saturn IB with an unmanned lunar module). Now Huntsville had to find out why the Saturn V's S-IC first stage bounced, why the S-II second stage turned off two of its engines, and why the S-IVB third stage refused to fire a second time. Meanwhile, Houston had to determine exactly how much shaking the lander could stand and why a large piece of the spacecraft-lunar module adapter had blown out during launch. Without satisfactory answers, the Saturn V might have to make a third unmanned flight.

POGO AND OTHER PROBLEMS

The pogo bounce had been observed (although to a much smaller degree) on *Apollo 4*, so its appearance during *Apollo 6* did not come as a complete surprise. Also, five years earlier, in 1963, pogo had threatened to end the Gemini program when the Titan II suffered this phenomenon on launch after launch. Its apparent cause was a partial vacuum created in the fuel and oxidizer suction lines by the pumping rocket engines. This condition produced a hydraulic resonance—more simply, the engine skipped when the bubbles caused by the partial vacuum reached the firing chamber. Sheldon Rubin of the Aerospace Corporation had finally suggested installing fuel accumulators and oxidizer standpipes, to ensure a steady flow of propellants through the lines. This had solved the Gemini launch vehicle problems, and NASA had this background experience to draw on when the Saturn V began having pogo troubles.*³⁹

* The Gemini launch vehicle engines were hypergolic, that is, its oxidizer and fuel burned on contact to produce thrust. Since the Saturn first stage (S-IC) engines were cryogenic, the propellant and oxidizer needed an igniter to produce burning—and no one expected a similar pogo problem with the larger booster.

Pogo on *Apollo 4* had been measured at one-tenth g, much less than the one-fourth g set as the upper limit in Gemini. The lower oscillation was probably the result of carrying just "a hunk of junk," to simulate lunar module weight, on the earlier flight. But a test article flown on *Apollo 6* had the shape and weight of a real lander in the adapter. This change in mass distribution coupled back into the fuel system problem and increased the pogo oscillations. The mission analysts later discovered that two of the Saturn engines had been inadvertently tuned to the same frequency, probably aggravating the problem. (Engines in the Saturn V cluster were to be tuned to different frequencies to prevent any two or more of them from pulling the booster off balance and changing its trajectory during powered flight.)

The rocketeers at Huntsville first wanted to know from Houston whether a crew could have withstood the vibration levels on *Apollo 6*. If so, the next Saturn V flight could be manned, even without a pogo cure. Low informed Saturn V Program Manager Arthur Rudolph that these levels could not be tolerated. Marshall also asked whether the emergency detection system could be used to abort the mission automatically if such high vibrations again occurred. During *Apollo 6*, the system had cast one vote for ending the mission. Had it cast a second vote, abort would have been mandatory. Low and chief astronaut Donald Slayton did not want to use the system in an automatic pogo abort mode. Low met with George H. Hage, Phillips' deputy, and they decided on the immediate development of a "pogo abort sensor," a self-contained unit that would monitor and display spacecraft oscillations. From what the sensor told him, a spacecraft commander could decide whether to continue or stop the mission.⁴⁰

Marshall Space Flight Center pulled an S-IC stage out of Michoud Assembly Facility, brought it to Huntsville, and erected it in a test stand. By May, Huntsville, Houston, and Washington Apollo officials were ready to attack the pogo problem. Hage agreed to head the activity until Eberhard Rees could finish his task on the command module at Downey and take over. At one time during the pogo studies, Lee B. James (who had replaced Rudolph as the Huntsville Saturn V manager) said, 1000 engineers from government and industry were working on the problem.⁴¹

Out on the West Coast, at the rocket engine test site at Edwards Air Force Base, Rocketdyne started testing its F-1 engine in late May. In the first six tests, helium was injected into the liquid-oxygen feed lines in an attempt to interrupt the resonating frequencies that had caused the unacceptable vibration levels. In four of the six tests, the cure was worse than the disease, producing even more pronounced oscillations. The Saturn V people at Marshall also tried helium injection, but their results were decidedly different. No oscillations whatsoever were observed. Tests using the S-IC stage's prevalves as helium accumulators were then conducted at both Edwards and Marshall. The prevalves were in the liquid-oxygen ducts just

CHARIOTS FOR APOLLO

above the firing chambers of the five engines and were used to hold up the flow of oxygen in the fuel lines until late in the countdown, when the fluid was admitted to the main liquid-oxygen valves in preparation for engine ignition. The prevalves were modified to allow the injection of helium into the cavity about 10 minutes before liftoff; the helium would then serve as a shock absorber against any liquid-oxygen pressure surges.

What had happened to the S-II and S-IVB stages, with two of the five J-2 engines shutting down in one case and the single J-2 engine refusing to start in the other, was more of a mystery than pogo. During tests at Arnold Engineering Development Center, at Tullahoma, Tennessee, engineers discovered that frost forming on propellant lines when the engines were fired at ground temperatures served as an extra protection against lines burning through. But frosting did not take place in the vacuum of space; the lines could have failed because of this. Also, in the line leading to each of the engines was an augmented spark igniter. Next to the igniter was a bellows. During ground tests, liquid air, sprayed over the exterior to cool it, damped out any vibrations. Vacuum testing revealed that the bellows vibrated furiously and failed immediately after peak-fuel-flow rates began. These lines were strengthened and modified to eliminate the bellows.⁴²

Another item noticed by the flight control monitors during the boosted flight of *Apollo 6* (and later confirmed by photographs) was that a panel section of the adapter that housed the lander had fallen away just after the Saturn V started bouncing. The controllers had been amazed that the structural integrity was sufficient to carry the payload into orbit. James Chamberlin in Houston discovered that thermal pressure (and therefore moisture) had built up in the honeycomb panels during launch; with no venting to allow the extra pressure to escape, the panel had blown out. A layer of cork was applied to the exterior of the adapter to keep it cooler and to absorb the moisture, and holes were drilled in the adapter panels to relieve the internal pressure if heat did build up inside on future launches.⁴³

Although Marshall was responsible for stability and dynamic structural integrity throughout the boost phase, the Manned Spacecraft Center could not afford to sit on the sidelines and watch while its sister center wrestled with these problems. Houston had to get an Apollo payload stack together for structural testing. On 16 May 1968, Low and James decided to use a "short stack" (the S-IC stage would be left out at this time but could be incorporated later).^{*} Astronaut Charles Duke was sent to Huntsville to keep information flowing between the centers, and Rolf Lanzkron was assigned

^{*} The stack comprised an S-IVB forward skirt, launch vehicle instrument unit, spacecraft-lunar module adapter, LM-2, a service module, a Block I command module, and the launch escape system from boilerplate 30.

by Low to manage the spacecraft dynamic integrity testing, which was satisfactorily completed on 27 August with no major hardware changes found necessary.⁴⁴

THE OUTLOOK

At midyear 1968, chances for landing on the moon within the decade were still touch-and-go. It did seem likely that NASA would have to fly only five, instead of six, preparatory flights that year, but one of these might have to be another unmanned Saturn V. Not knowing exactly what would follow the third mission of the year (a manned Saturn IB launch) caused some extra planning. For example, the Kennedy spacecraft preparation team had to prepare both a boilerplate and a qualified production command module for the next Saturn V shot, since the choice for launch depended on the outcome of the pogo investigations. Mission planners in Washington also revived the plan for launching two Saturn IB missions to give both the North American and the Grumman spacecraft a workout in earth orbit, if another unmanned Saturn V had to be flown.⁴⁵ Even this plan was tentative, however, as the delivery date for LM-3 was still not firm.

On the brighter side of the ledger at mid-year was North American's work in getting CSM-101 ready for the first manned Apollo mission. Although the contractor was late in shipping the craft from its California factory to the Florida launch site, improvements in the fabrication of this machine indicated that future spacecraft should be on time. After a traumatic and pressure-packed 18 months, North American was finally delivering satisfactory, flight-ready hardware. When 101 arrived at the Cape on 30 May, the receiving inspectors found fewer discrepancies than on any spacecraft previously delivered to Kennedy.⁴⁶

Mueller had told the Senate space committee in February 1968 that the first manned Apollo mission would be flown in the last quarter of the year.⁴⁷ In June, this still seemed feasible.

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11

Tastes of Triumph

1968: Second Half

The interval between the manned flights of Gemini and Apollo was less than two years (November 1966 to October 1968), about the same as that between Mercury and Gemini (May 1963 to March 1965). But before Apollo flew, the days were filled with more trauma, troubleshooting, and toil. Asked by a former college classmate to give an address, Houston Apollo manager George Low replied that he could not—he was already spending so much time with Apollo that his own family hardly saw him. That was only a slight exaggeration. For more than a year, his staff meetings had been crammed full of items that needed his personal attention. Every Friday without fail there were spacecraft configuration control meetings, leaving only Saturdays to visit the Downey and Bethpage plants to check on progress.

Shortly after midyear 1968, the feeling of dashing from one problem to another started to fade. George Mueller, manned space flight chief in Washington, was told at a monthly management council meeting that North American's command module 103 was moving through checkout operations at such an excellent pace that it would almost certainly be able to make a manned Saturn V mission before the end of the year.¹

Now that such a flight seemed probable in 1968, there was sobriety, as well as elation, among Apollo workers. Apollo 7, they knew, would be the last of the Saturn IB missions in mainline Apollo. Saturn IB vehicles 206 through 212 were released to a follow-on Apollo Applications Program, although that project was faring none too well in Congress for fiscal 1969

CHARIOTS FOR APOLLO

money. Thus, ironically, even before the first astronauts lifted off the ground in Apollo, a problem in worker morale began to surface.* Low commented:

There has been increasing concern by the people in [the Apollo Spacecraft Program Office], as well as others at the center, about what we will do after we land on the moon. In light of recent budget decisions, many of our people are concerned about the future of [the Manned Spacecraft Center].²

But the members of the Apollo team who were working on the lunar module had little time to think about the future. Mueller and his deputy, Samuel Phillips, told Grumman officials in July that the launch vehicle and the command module were in good shape but too many changes were still being made in the lunar module. Unless Grumman speeded up its work considerably, it was going to be far behind everyone else.³

When LM-3, listed as the first to be manned, reached the Cape on 14 June, the receiving inspectors found more than 100 deficiencies. Many were major. After more than a month of inspecting, checking, and testing, George C. White, reliability and quality assurance chief at NASA Headquarters, reported 19 areas—including stress corrosion, window failures, and wire and splice problems—that Mueller's Certification Review Board would have to consider. Charles Mathews, former Gemini manager in Houston and now working for Mueller in Washington, made a quick trip to Florida. In Mathews' opinion, the work that Rocco Petrone's launch operations team at Kennedy Space Center would have to do was far beyond what should have been required.⁴ This lack of a flight-ready lunar module forced Apollo planners to try for some short cuts on the route to the moon.

PROPOSAL FOR A LUNAR-ORBIT MISSION

Almost as soon as NASA adopted an alphabetical stairway for reaching the moon in progressive flights (see Chapter 9, pp. 234–35), with the seventh, or G, step representing the ultimate goal, mission planners had begun looking for ways to omit a letter. In late 1967, when the ABC-scheme evolved, Low and Flight Operations Director Christopher Kraft had pushed for a lunar-orbital mission as soon as possible to learn more about communi-

* Morale problems among agency workers arose at different points in the Mercury and Gemini programs. Mercury ended abruptly in June 1963 (after six manned flights). Most of the personnel simply moved on into Gemini or Apollo positions. Gemini suffered its morale drop after eight of its ten manned flights, and the scramble for new jobs in mid-1966 was more frantic than it had been three years earlier. The problems of hiring and firing in industry for short-term programs such as space and weapon system projects have never really been resolved. And the same is essentially true for federal agencies.

cations, navigation, and thermal control in the deep space environment.

In the spring of 1968, Apollo officials in Houston were trying to upgrade the E mission (operating the command module and the lander in high-earth orbit) into something called E-prime, which would move the mission to the vicinity of the moon. But by August Gilruth and others had concluded that LM-3 would not be ready for flight that year. This finding left NASA with two excellent command modules, 101 and 103, but no lunar module companions. Low had already recognized this likelihood in July, after Kennedy found the many deficiencies in LM-3. If a lunar module could not be manned in 1968, he reasoned that Saturn V 503 and CSM-103 might be used for a circumlunar or lunar-orbit flight. Low kept his own counsel for a while, waiting for the Saturn V pogo problem to be resolved.

On 7 August, Low asked Kraft to work out a flight plan for such a mission during 1968. Then the Houston manager, accompanied by Carroll Bolender, Scott Simpkinson, and Owen Morris, went to the Cape on 8 August to talk with Phillips, Kennedy Director Kurt Debus, Petrone, and Roderick Middleton about the status of Saturn V 503. The Cape contingent believed it could launch the big Saturn in January 1969.⁵

Back in Houston the next day, 9 August, MSC Director Gilruth had hardly entered his office before Low began telling him his ideas for a lunar-orbit mission. Gilruth, too, was enthusiastic, and he and Low started calling Washington, Huntsville, and the Cape to set up a meeting that same afternoon at Marshall. Low next talked to Kraft, who said the mission was feasible from a ground control and spacecraft computer standpoint. Gilruth, Low, Kraft, and Flight Crew Operations Director Donald Slayton then boarded a plane for Huntsville. At 2:30, they were joined by Debus and Petrone from Kennedy and Phillips and George Hage from Headquarters. Making an even dozen were the Marshall hosts, Wernher von Braun, Eberhard Rees, Ludie G. Richard, and Lee James.

Low said that a lunar-orbit mission, if it could be flown in December, might be the only way to meet the fast-approaching lunar landing deadline. This remark sparked a lively discussion. The talk was mostly about what each of the NASA elements would have to do to make the mission possible in the time remaining. Debus and Petrone considered Kennedy's workload and concluded that they could be ready by 1 December; von Braun, Rees, James, and Richard reported that they had nearly solved the pogo problem; and Low and Gilruth talked about the differences between command modules 103 and 106 (the first spacecraft originally scheduled to go to the moon) and what to use as a substitute for the lander.

Even as he joined in the discussion, Apollo Program Director Phillips had been taking notes. He said they should keep their plans secret until a decision was made by NASA's top officials. In the meantime, while gathering whatever information was needed, they would use the code name "Sam's Budget Exercise" as a cover. The conferees would meet in Washington on

CHARIOTS FOR APOLLO

14 August—"Decision Day." Administrator James Webb and Mueller would be in Vienna attending the United Nations Conference on the Exploration and Peaceful Uses of Outer Space at that time. If the Washington meeting decided in favor of the lunar-orbit mission, Phillips would fly to Austria to sell the idea to Webb and Mueller.⁶

In Houston at 8:30 that evening, Low met with spacecraft chiefs Kenneth Kleinknecht and Bolender, technical assistant George Abbey, and North American Apollo manager Dale Myers. Kleinknecht began studying the differences between spacecraft 103 and 106, Bolender left for Bethpage to find a substitute for LM-3, and Myers went back to Downey to make sure that command module 103 was moving along and to oversee any changes Kleinknecht recommended. Joseph Kotanchik, structures expert in Houston, could not see any reason for Bolender's trip to Bethpage; a simple cross-beam could be used for weight and balance, he said. But Kotanchik found himself alone in this position. The others believed that a true facsimile should be carried, and Low decided on a lunar test article.

Early on Monday morning, 12 August, Kraft told Low that the target date would have to be 20 December if they wanted to launch in daylight. If the flight had to be terminated for any reason shortly after launch, good visibility was necessary for recovering the spacecraft. In the meantime, Slayton had been thinking about which crew to pick for the flight. Frank Borman's team had been training for a high-altitude mission. Slayton talked with Borman over the weekend and decided to propose that crew at the meeting in Washington.⁷

The 12 men who had gathered in Huntsville were joined by William Schneider and Julian H. Bowman when they met with Deputy Administrator Thomas O. Paine* at Headquarters on Wednesday, 14 August. Low reviewed spacecraft status, Kraft discussed flight operations, and Slayton talked about flight crew preparations. Von Braun reported that the Saturn would be ready for the launch, and he and Rees agreed that Low had made a good selection of a stand-in for the lunar module. Debus and Petrone said the Cape could launch the Saturn V by 6 December.⁸

After listening to the plotters, Paine decided to play devil's advocate. Not too long ago, he said, you people were trying to decide whether it was safe to man the third Saturn V (503), and now you want to put men on top of it and send them to the moon. The Deputy Administrator then asked for comments. This is what he heard:

* After being first Associate and then Deputy Administrator of NASA for more than seven years, Robert Seamans (who originally intended to stay only two years) resigned on 2 October 1967 and left the agency on 5 January 1968. On 31 January, President Lyndon Johnson announced the nomination of Paine, a General Electric official, to replace Seamans. Paine was confirmed by the Senate on 5 February and sworn into office on 25 March.

TASTES OF TRIUMPH

- Von Braun: Once you decided to man 503, it did not matter how far you went.
- Hage: There are a number of places in the mission where decisions can be made and risks minimized.
- Slayton: It is the only chance to get to the moon before the end of 1969.
- Debus: I have no technical reservations.
- Petrone: I have no reservations.
- Bowman: It will be a shot in the arm for manned space flight.
- James: Manned safety in this and following flights will be enhanced.
- Richard: Our lunar capability will be advanced by flying this mission.
- Schneider: The plan has my wholehearted endorsement.
- Gilruth: Although this may not be the only way to meet our goal, it does increase the possibility. There is always risk, but this is a path of less risk. In fact, the minimum risk of all Apollo plans.
- Kraft: Flight Operations will have a difficult job here. We need all kinds of priorities—it will not be easy to do, but I have confidence. But it should be a lunar orbit and not a circumlunar flight.
- Low: Assuming Apollo 7 is a success, there is no other choice.⁹

So ended the round table vote, by the men who managed the day-to-day details of the Apollo program, to commit the first crew to fly to the moon. Paine was impressed, but he was only the first of the three top men who had to be convinced. Webb and Mueller would not be so easy to sell. In fact, when Mueller called Phillips from Vienna during the meeting and learned of the plan, he was not receptive. He urged Phillips not to come to Vienna. By the next day, 15 August, he had warmed to the idea, but he wanted Phillips to keep it quiet until after Apollo 7. Webb was shocked by the audacity of the proposal and was inclined to say no immediately. After talking with Phillips and Paine, however, he asked for more information.

Paine called Willis H. Shapley, Julian Scheer, and Phillips in to draft a text for Webb. Paine's cable to Vienna on 15 August underlined his complete support and included an item-by-item schedule of necessary actions. The cable also contained a draft of a statement for Webb to make in Vienna and a draft of a press release to be issued in Washington. Altogether, the cablegram covered seven typewritten pages.¹⁰

After discussing the proposal with Mueller, Webb cabled Paine on 16 August that he believed it unwise for any announcement to originate from Vienna. Webb told his deputy to plan for the lunar-orbit flight but to make no public statement about it. In other words, NASA could not talk about anything but an earth-orbital mission. Webb also asked Paine to notify the White House and the President's scientific advisers about any drastic changes in mission planning. This was not what the planners had asked for, but it

CHARIOTS FOR APOLLO

was certainly more than Webb had given them the previous day. Now they had to figure out how to stay within the constraints set by the Administrator and still get everything ready for a lunar-orbit mission if approval came later. Phillips called Low, saying he would be in Houston the next day to decide how to handle the situation.¹¹

Phillips and Hage arrived in Houston on 17 August and met with Gilruth, Low, Kraft, and Slayton. The Apollo program leader from Washington said that Webb had given him clear authority to prepare for a 6 December launch, to designate it as a C-prime mission, and to call it Apollo 8. He then ticked off what else had been authorized: they could assign Borman's crew to the flight, equip and train it to meet the 6 December launch, and speak of the flight as earth-orbital while continuing to plan for a lunar orbit. The plotters were well aware, and Phillips reemphasized it, that a successful command module qualification flight in earth orbit by Apollo 7 was the key to the first lunar flight's being approved for 1968.¹² Now Houston had to train crews to fly that mission, as well as the others that would follow.

SELECTING AND TRAINING CREWS

Early in 1961, Robert B. Voas at the Manned Spacecraft Center had written a paper on how pilots should train for a lunar mission and what they should do during the flight. Because of the hostile environment and the inability to return quickly to safety, Voas said, crews had to be prepared to stay with their ships and keep the protective systems operating. That made good sense. Moreover, since modifications were made in spacecraft systems almost until time of launch, a crew would have to follow its specific spacecraft through step-by-step testing in the factory and through preparations for flight at the launch site.

Crew tasks in flight included steering the space ship, but this was not a constant duty. Steering was needed mainly during launch, lunar maneuvers, and earth reentry and landing. Navigating the ship from the earth to the moon and back required high-speed automatic computing, during which the crew would choose data fed into the computer and verify the results on the navigation system displays. In addition, the crew would make optical sightings, orient trackers on selected stars, and navigate manually, using prepared tables and a simple computer. The astronauts would maintain a continuous check on subsystems, which meant one crewman keeping watch while the others slept. This chore might include such things as switching to a redundant system if a component failed and keeping the ground informed on mission status. During early flights, scientific activities on the moon would be limited to observing systems (a primary task of a test pilot,

anyway) and conducting some medical and biological experiments. Equipment for astronomical and lunar surface studies would consist of whatever could be carried to the moon and set up fairly easily by pressure-suited astronauts. Crew positions were to be commander pilot, navigator copilot, and engineer-scientist. (In June 1967, these titles were changed to commander, command module pilot, and lunar module pilot.) * ¹³

In 1966, before the Apollo 204 fire, a number of astronauts were assigned to crew positions in Apollo. On 21 March, Gus Grissom, Edward White, and Roger Chaffee (backed up by James McDivitt, David Scott, and Russell Schweickart) were picked to man the first flight. On 29 September, Walter Schirra, Donn Eisele, and Walter Cunningham were named for the second flight, with backups Frank Borman, Thomas Stafford, and Michael Collins. Up to that point, keeping track of assignments was not difficult, but it soon changed. If the Grissom group circled the earth for up to 14 days, why should Schirra's crew do the same thing? So Schirra's flight was canceled in December, and his team was assigned as backup for Grissom's. McDivitt's and Borman's crews soon had new assignments. The McDivitt trio (backed by Stafford, John Young, and Eugene Cernan) drew the second flight, a complex dual mission with two launch vehicles (Saturn IBs 205 and 208) that entailed putting the command module and lunar module through maneuvers in earth orbit. Borman's threesome, with William Anders replacing Stafford (who now had a command of his own) and Charles Conrad, Richard Gordon, and Clifton Williams backing them, snared the first manned flight scheduled to be launched by a Saturn V. Borman's launch vehicle would be 503, the third in the series. At the end of 1966 this was the pilot assignment picture.¹⁴

Immediately after the fire in January 1967, Webb canceled all crew assignments. On 9 May, however, as NASA began to recover from the tragedy, he told the Senate space committee that Schirra, Eisele, and Cunningham (with Stafford, Young, and Cernan as backups) would fly the first manned Apollo mission.† Schirra's group, Webb told the senators, was on its way to the Downey plant "to start a detailed, day-by-day, month-by-month association with Block II spacecraft No. 101."¹⁵

* There had been other names for the crew positions. In 1966, for example, when the Grissom and Schirra crews were in training, the terminology was command pilot, senior pilot, and pilot.

† An innovation for Apollo manned flights was the support crew. For Apollo 7, this would be John Swigert, Ronald Evans, and William Pogue. Perhaps their most important duty was coordinating and maintaining the Flight Data File, which included the flight plan, checklists, and mission ground rules, making sure that these were kept up to date and that the other crews were informed of changes. The support crews used the simulators to work out procedures, especially for emergency situations. Thus, when the prime and backup teams trained on the simulators, procedures were ready and they could devote their time to mastering them. In countdown tests, the support crews set up the cockpit, making sure that all switches were in the proper positions. Swigert, Evans, and Pogue also stood by during spacecraft tests on the pad, to assist the prime or backup crew to get out in case of emergency.

CHARIOTS FOR APOLLO

Shortly after the *Apollo 4* flight, on 20 November 1967, NASA announced the names of two more crews. McDivitt's team, with new backups Conrad, Gordon, and Alan Bean,* would still fly the earth-orbital command and lunar module mission they had been given the previous year. The support team was Edgar Mitchell, Fred Haise, and Alfred Worden. Borman's crew again drew the high-altitude maneuvers, but the backups were now Neil Armstrong, James Lovell, and Edwin Aldrin, with a support team of Thomas Mattingly, Gerald Carr, and John Bull.¹⁶

In November 1967, therefore, flight crew appointments seemed to be set for all of 1968 and part of 1969, but 1968 was an eventful year for men as well as machines. The major change, of course, was the proposal to attempt a lunar-orbit mission on the second manned Apollo flight. NASA planners reasoned that Borman's crew was already training for operations with the command module as far as 6400 kilometers from the earth. The astronauts would have to stretch that distance to nearly 380 000 kilometers, but they would not have the lunar module to complicate their training. On the other hand, McDivitt's group appeared to have a tremendous task, training to put the lander through its paces for the first time.

Collins, in his book *Carrying the Fire: An Astronaut's Journeys*, said that Slayton asked McDivitt if he wanted to fly the circumlunar (or lunar-orbit) mission, but McDivitt turned it down. He and his crew had spent hundreds of hours learning to handle the lunar module, and he would rather not see that time wasted. The crews would have to exchange command modules, though. Spacecraft 103, on which the McDivitt team had been training, would be ready for a flight in 1968 and 104 would not. Scott complained about that, since as command module pilot he had been living with his machine and knew its characteristics well. Collins, who had been similarly occupied with 104, had other, more personal, worries.¹⁷

In the summer of 1968, two astronauts with flight assignments came up with medical problems that stimulated another rash of changes. Collins, from Borman's team, needed surgery to remove a bone spur from his spine. Lovell moved from the backup team to take over from Collins, Aldrin switched from lunar module to command module pilot on the backup team to replace Lovell, Haise shifted from the support group on McDivitt's team to backup lunar module pilot in Borman's group in place of Aldrin, and Jack Lousma joined McDivitt's support team as a substitute for Haise. So Collins' bone spur started a whole round of musical chairs in flight positions. And the game continued when Borman lost a member of his support team. Bull resigned from the corps because of a pulmonary problem, and Vance Brand filled his seat.¹⁸

Schirra's Apollo 7 group had remained intact. For almost a year, the

* Clifton Williams, the third member of McDivitt's backup crew, had been killed in a T-38 aircraft crash on 5 October 1967 and was replaced by Bean.

group had stayed with the spacecraft in California. When the spacecraft moved to Florida in June 1968 for launch preparations, the crew followed. The astronauts had not devoted all their time to CSM-101, however. During the six months before launch in October 1968, they had spent nearly 600 hours in the command module simulator, operating the 725 manual controls and reacting to simulated emergencies and malfunctioning systems. They had also been in the spacecraft during an altitude chamber test, checked out the slide wire for a launch pad emergency escape test, crawled out of a model spacecraft in the Gulf of Mexico to practice recovery, listened to briefings on systems and experiments, visited the Morehead Planetarium in North Carolina and the Griffith Planetarium in California for celestial navigation training, worked with the crew systems people in getting their suits and supporting equipment ready, and studied mission plans and other documentation.¹⁹

Schirra's team also received the benefit, through briefings or written reports, of the activities of other astronauts who were studying, participating in, or training on specific pieces of the Apollo systems. For example, before CSM-101 left the factory at Downey, it went through a test to make sure that its systems performed properly and in harmony. Astronaut John Young attended this session and noted that, in some instances, the computer, inverters, pumps, fans, and radios were in his opinion operated longer than was either necessary or good for the equipment. He also found that, when deficiencies were uncovered, everything stopped while discrepancy reports were written on the spot. On the positive side, however, Young thought the crew checklist for time-critical sequences was excellent. From there he went on, item by item, finally concluding "that S/C 101 is a pretty clean machine." Schirra, McDivitt, and Borman all were given copies of his report.²⁰

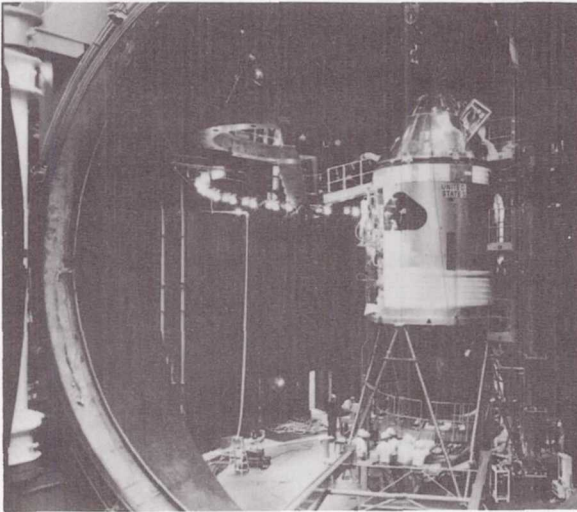
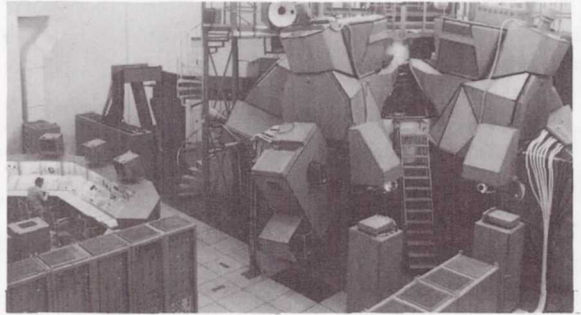
The Schirra crew had practiced getting out of the spacecraft in the Gulf to simulate recovery, but Lovell, Stuart Roosa, and Charles Duke made a more extensive test to find out how they and the craft would fare if recovery were delayed as much as 48 hours. They especially wanted to see how quickly the spacecraft could right itself if it flipped over in the water with its nose down—the "stable II" position. ("Stable I" was the normal upright position.) So Lovell and the others were tossed into the water upside down. They had no trouble getting to the manual control switch that signaled three air bags to inflate and turn the ship over. During the ensuing hours, the crewmen were cool enough, but water sometimes splashed in through a postlanding air vent. They used the urine-collection hose to vacuum the water from the cabin deck and dump it overboard. All in all, they agreed, the craft was seaworthy enough for a prolonged wait until recovery.²¹

Two days on the water might be a contingency exercise, but a week in the vacuum chamber was not. Except for weightlessness, the Space Environment Simulation Laboratory at the Manned Spacecraft Center could repro-



Schirra, Eisele, and Cunningham (left to right) practice climbing out of the spacecraft into a life raft, to perfect recovery procedures.

The Apollo command module mission simulator (right) at Manned Spacecraft Center, where Apollo astronauts practiced for their missions. Another simulator was at Kennedy Space Center.



Command and service modules 2TV-1 in the space environment simulation chamber at Manned Spacecraft Center. Hinges for the huge door to close the chamber are at extreme left. Astronauts Kerwin, Brand, and Engle spent a week in this craft under operational space conditions in 1968.

duce most of the conditions of space. In a test vehicle called "2TV-1" (which, except for some flight-qualified equipment, was identical to Schirra's CSM-101), Joseph Kerwin, Vance Brand, and Joseph Engle looked for things that might be wrong with the craft. They found the vehicle satisfactory in most respects, but they still managed to fill 14 pages with comments. They noted particularly that the water lines sweated and drops puddled on the cabin deck. Otherwise the environmental system kept them

comfortable. The test group went on to discuss communications (some headsets worked fine, others did not), the rest periods (the men slept well), the water (they advised not drinking it for two hours after chlorination), and the food (some of the package seams split). All the astronauts received copies of this paper.²²

In addition to their flight training, the Apollo 7 crews had to exercise to keep physically fit, to guard themselves against illness, and to fly their T-38 jet aircraft from place to place to maintain proficiency in high-performance machines. Schirra, Eisele, and Cunningham had been doing this detailed work, with only an occasional night off to see a soccer match or some other sports event, for more than a year. CSM-101 had spent even longer getting ready for its voyage.

Apollo 7: THE MAGNIFICENT FLYING MACHINE

CSM-101 started through the manufacturing cycle early in 1966. By July, it had been formed, wired, fitted with subsystems, and made ready for testing. After the fire in January 1967, redefinition forced changes, mainly in the wiring, hatch areas, and forward egress tunnel. It was December before the spacecraft came back into testing. CSM-101 passed through a three-phase customer acceptance review; during the third session, held in Downey on 7 May 1968, no items showed up that might be a "constraint to launch." North American cleared up what few deficiencies there were (13) and shipped the craft to Kennedy on 30 May.²³

Low had spent a lot of time thinking about a flight to the moon before 1968 ended, but Apollo 7 still was given his close attention. He probably worried about that flight more than those that followed because the earlier attempt to get a crew skyborne had ended in disaster. After rereading the evaluations of the fourth, fifth, and sixth missions, Low asked Simpkinson, one of his chief troubleshooters, to make up a "worry list" of things that might have been overlooked. He also asked John Hodge's Crew Safety Review Board to question all the "judgment decisions" that separately had made good sense, making sure that the sum of them still did. Aaron Cohen, who reviewed them for Low, concluded that, individually and collectively, these decisions had been sound. Out at North American, Dale Myers was doing the same soul-searching, looking specifically at the 137 changes that had resulted from the spacecraft 012 fire.²⁴

All this care paid off. At the Flight Readiness Review on 20 September, Myers reported that CSM-101 was "a very good spacecraft." Walter J. Kapryan of Kennedy said the launch preparations people agreed.²⁵ Now it was up to the flight crew to prove them right.

In October 1968, Schirra, a veteran of both Mercury and Gemini, found himself facing a situation similar to some he had encountered in

CHARIOTS FOR APOLLO

previous Octobers. In 1962, his Mercury-Atlas 8 mission had been a six-orbit engineering test to see if Mercury's legs might be stretched to a full day's flight; three years later his *Gemini VI* had been an engineering test to attempt the first rendezvous with a second vehicle in space.

The primary objectives for Apollo 7, also an engineering test flight, were simple: "Demonstrate CSM/crew performance; demonstrate crew/space vehicle/mission support facilities performance during a manned CSM mission; demonstrate CSM rendezvous capability."

Phillips wrote Webb that these objectives could be met within 3 days but that the mission would be open-ended up to 11 days "to acquire additional data and evaluate the aspects of long duration manned space flight." This did leave some time for taking pictures of weather and terrain that might be of interest to the scientific community.²⁶

One piece of equipment got aboard Apollo 7 and all subsequent manned flights in spite of the insistence of most engineers that it was not needed and the ambivalence of the test-pilot-oriented crews. This was the television camera. Ever since September 1963, when NASA had first directed North American to install a portable camera in the spacecraft, that device had been going in and out of the craft as though it were caught in a revolving door. Wrestling with the constant problem of overweight, many engineers viewed television cameras only as nice things to have. On occasions when kilograms, and even grams, were being shaved from the command module, the camera was among the first items to go. There were those, however, who persistently argued for the inclusion of television.

NASA personnel in charge of public information activities—Julian Scheer in Washington and Paul P. Haney in Houston—naturally favored the use of television, but there was one management-level engineer in the Houston Apollo office who agreed with them. In the spring of 1964, William A. Lee wrote:

I take typewriter in hand to plead once more for including in-flight TV. . . . Since [it] has little or no engineering value, the weight penalty must be assessed against a different set of standards. . . . One [objective] of the Apollo Program is to impress the world with our space supremacy. It may be assumed that the first attempt to land on the moon will have generated a high degree of interest around the world. . . . A large portion of the civilized world will be at their TV sets wondering whether the attempt will succeed or fail. The question before the house is whether the public will receive their report of this climactic moment visually or by voice alone.²⁷

Four springs later, following more trips through the revolving door, television became part of Apollo when Phillips told Low to install a camera on CSM-101.²⁸

As the Apollo 7 crew and its guests ate the traditional launch-day breakfast, a few nostalgic thoughts flitted through the minds of at least some present. For at least two members of the morning get-together, the thoughts had to be tinged with sadness. On 16 September, to the surprise of nearly everyone, Webb had announced that he was retiring on 6 October, his 62d birthday. After almost eight years at the helm of NASA, Webb stepped down, apparently to smooth the transition to a new administration in the White House. Paine, his deputy, became acting administrator. Four days after the Webb announcement, Schirra said this would be his last mission, as he, too, planned to retire.²⁹

So feelings of regret mixed with anticipation as more than 600 news media representatives watched the first manned Apollo flight—*Apollo 7*—speed skyward from Launch Complex 34 a few minutes after 11:00 on the morning of 11 October. Once Saturn IB 205 and CSM-101 (the first Block II CSM) cleared the pad in Florida, a three-shift mission control team—led by flight directors Glynn Lunney, Eugene Kranz, and Gerald D. Griffin—in Houston took over. Schirra, Eisele, and Cunningham inside the command module had listened to the sound of propellants rushing into the firing chambers, had noticed the vehicles swaying slightly, and had felt the vibrations at ignition. Ten and a half minutes after launch, with little bumpiness and low g loads during acceleration, *Apollo 7* reached the first stage of its journey, an orbital path 227 by 285 kilometers above the earth.

A few hours later, as the spacecraft separated from the S-IVB stage and then turned back in a simulated docking approach, Cunningham described the S-IVB, which would be used for rendezvous target practice the next day. The spacecraft–lunar module adapter panels, he said, had not fully deployed—which naturally reminded Stafford, on the capsule communicator (CapCom) console, of the “angry alligator” target vehicle he had encountered on his *Gemini IX* mission. This mishap would have been embarrassing on a mission that carried a lunar module, but the panels would be jettisoned explosively on future flights.³⁰

After this niggling problem, service module engine performance was a joy. This was one area where the crew could not switch to a redundant or backup system; at crucial times during a lunar voyage, the engine simply had to work or they would not get back home. On *Apollo 7*, there were eight nearly perfect firings out of eight attempts. On the first, the crew had a real surprise. In contrast to the smooth liftoff of the Saturn, the blast from the service module engine jolted the astronauts, causing Schirra to yell “Yabada-badoo” like Fred Flintstone in the contemporary video cartoon. Later, Eisele said, “We didn’t quite know what to expect, but we got more than we expected.” He added more graphically that it was a real boot in the rear that just plastered them into their seats. But the engine did what it was supposed to do each time it fired.³¹

CHARIOTS FOR APOLLO

With few exceptions, the other systems in the spacecraft operated as they should. Occasionally, one of the three fuel cells supplying electricity to the craft developed some unwanted high temperatures, but load-sharing hookups among the cells prevented any power shortage. The crew complained about noisy fans in the environmental circuits and turned one of them off. That did not help much, so the men switched off the other. The cabin stayed comfortable, although the coolant lines sweated and water collected in little puddles on the deck, which the crew expected after the Kerwin team's test in the altitude chamber. Schirra's crew vacuumed the excess water out into space with the urine dump hose.³²

Visibility from the spacecraft windows ranged from poor to good, during the mission. Shortly after the launch escape tower jettisoned, two of the windows had soot deposits and two others had water condensation. Two days later, however, Cunningham reported that most of the windows were in fairly good shape, although moisture was collecting between the inner panes of one window. On the seventh day, Schirra described essentially the same conditions.

Even with these impediments, the windows were adequate. Those used for observations during rendezvous and stationkeeping with the S-IVB remained almost clear. Navigational sighting with a telescope and a sextant on any of the 37 preselected "Apollo" stars was difficult if done too soon after a waste-water dump. Sometimes they had to wait several minutes for the frozen particles to disperse. Eisele reported that unless he could see at least 40 or 50 stars at a time he found it hard to decide what part of the sky he was looking toward. On the whole, however, the windows were satisfactory for general and landmark observations and for out-the-window photography.³³

Most components supported the operations and well-being of the spacecraft and crew as planned, in spite of minor irritations like smudging windows and puddling water. For example, the waste management system for collecting solid body wastes was adequate, though annoying. The defecation bags, containing a germicide to prevent bacteria and gas formation, were easily sealed and stored in empty food containers in the equipment bay. But the bags were certainly not convenient and there were usually unpleasant odors. Each time they were used, it took the crew member from 45 to 60 minutes, causing him to postpone it as long as possible, waiting for a time when there was no work to do. The crew had a total of only 12 defecations over a period of nearly 11 days. Urination was much easier, as the crew did not have to remove clothing. There was a collection service for both the pressure suits and the inflight coveralls. Both devices could be attached to the urine dump hose and emptied into space. They had half expected the hose valve to freeze up in vacuum, but it never did.³⁴

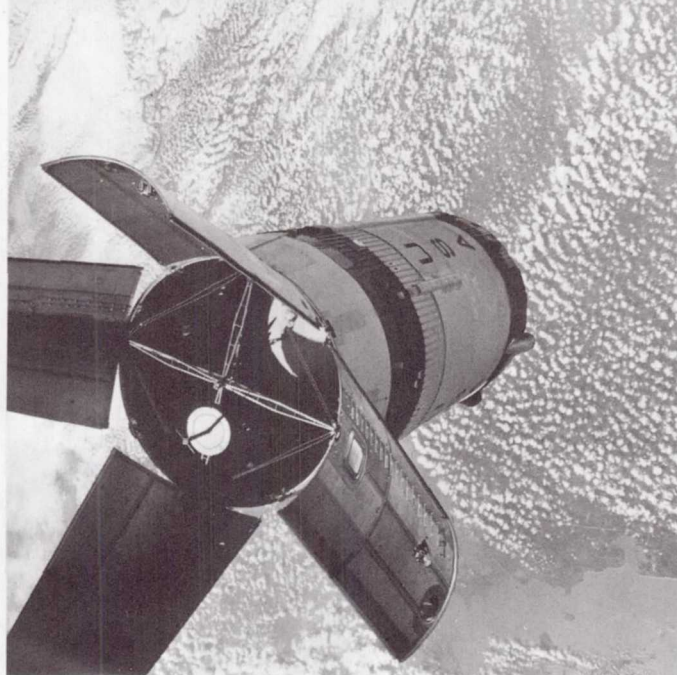
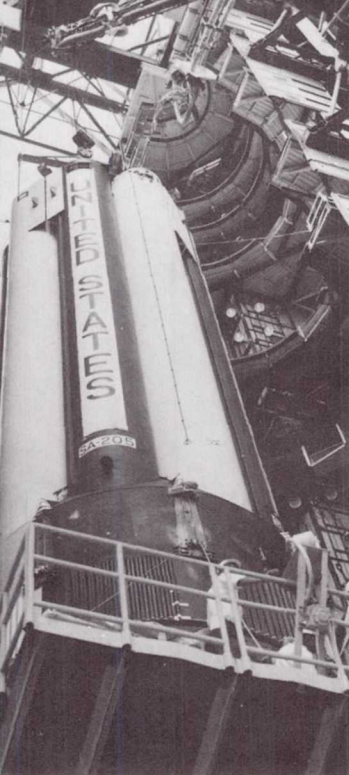
The astronauts finally had a spacecraft large enough to move about in. During Gemini, crewmen had gone outside the craft in an exercise called

extravehicular activity, or EVA. In Apollo, quite naturally, the abbreviation became IVA, for intravehicular activity. The crew adapted easily to this new free-floating realm. Schirra said, "All the problems we worried about the spacecraft picking up motions from the crew, no such thing. . . . You get to be quite a gymnast." And Cunningham later added, "The work is almost zero, and you can move any place you want to very freely, and you certainly don't need strong handholds to take care of it." The crew found exercise was important. At first, when the men slept in the couches their bodies curled up into the fetal position, which gave them lower back and abdominal pains. So they almost raced each other for a workout on a stretching device called an Exer-Genie, which relaxed their cramped and aching muscles.³⁵

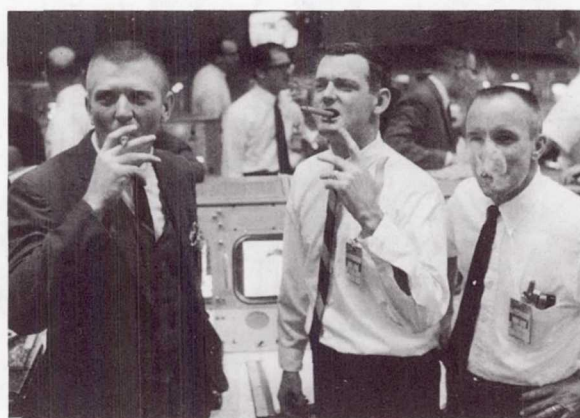
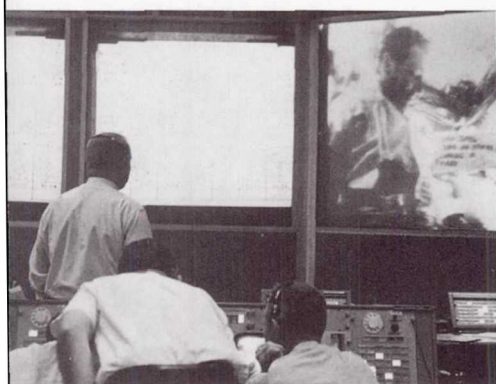
The crew slept well enough, but Schirra complained about round-the-clock operations that disrupted the normal, earth-bound routine. Sleep periods might start as early as 4:00 in the afternoon or as late as 4:00 in the morning. Slayton suggested that all three astronauts sleep at the same time, but Schirra said the machine was flying well and he did not want to make any changes. So Eisele kept watch while the others slept, and then he went to bed. Two sleeping bags were underneath the outboard couches (the center couch could be moved out of the way), and the crewmen could zip themselves into them, wearing their flight coveralls. The bags were not popular, because, they said, the restraints were in the wrong places. Cunningham preferred sleeping in the couch, strapping himself down with a shoulder harness and a lap belt. If two crewmen slept in the couches at the same time, however, one of them was always in the way of spacecraft operations. After the third day, the crew had worked out a routine that allowed all of them to get enough sleep.³⁶

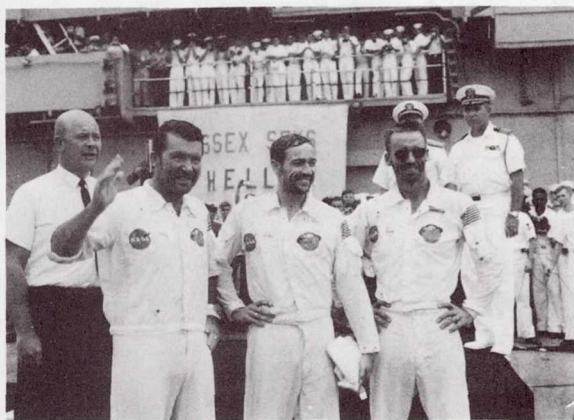
Although the astronauts had more than 60 food items to choose from, giving them about 2500 calories a day, they were not happy with their fare. The bite-size food crumbled and stray particles floated around the cabin. They almost came to hate the high-energy sweets and tried to talk each other out of the more satisfactory breakfast items. Following his Gemini flight, Schirra had said that if he flew on Apollo he was going to take some coffee with him. And he did. During flight and later, the crew emphasized that space food was a long way from satisfying their normal table habits.³⁷

The astronauts did use the controversial television camera to show their colleagues in mission control and the public everywhere how they got along in their living quarters, operated the spacecraft, ate, and swam about in the weightlessness of space. When flight plan changes crowded their schedule, Schirra canceled the first of several planned television demonstrations. Slayton tried to change his mind, but the spacecraft commander told him sharply that there would be no show that day. The programs finally began, however, and the crew appeared to enjoy them, using cue cards—"Keep Those Cards and Letters Coming In, Folks" and "Hello from the Lovely Apollo Room



Apollo 7, first manned Apollo flight, 11–22 October 1968. The Saturn IB, like earlier launch vehicles, was assembled at the launch pad. Above left, Saturn 205's first stage rests on the pedestal at Launch Complex 34 before mating with other stages for launch. After launch and a rendezvous maneuver, the Apollo 7 crew examines the Saturn's S-IVB stage (above right) that had placed them in orbit. Meeting no problems in the maneuver, the crew concluded that future pilots would have no difficulty docking with the lunar module. Below left, Mission Control watches the first live television beamed by an American spacecraft, as Eisele and Schirra signal, "Keep Those Cards and Letters Coming in, Folks." At the end of the nearly 11-day mission, flight controllers Gene Kranz, Glynn Lunney, and Gerald Griffin (left to right below with cigars) celebrate splashdown.





A grizzled but happy Apollo 7 crew—Schirra, Eisele, and Cunningham (left to right)—greets the crew of recovery ship U.S.S. Essex. Donald Stullken, inventor of the flotation collar attached to the spacecraft during recovery, is at the extreme left.

High Atop Everything”—supplied by Michael Kapp,* who also provided cassettes for their musical enjoyment.³⁸

Some of the crew's grumpiness during the mission could be attributed to physical discomfort. About 15 hours into the flight, Schirra developed a bad cold, and Cunningham and Eisele soon followed suit. A cold is uncomfortable enough on the ground; in weightless space it presents a different problem. Mucus accumulates, filling the nasal passages, and does not drain from the head. The only relief is to blow hard, which is painful to the ear drums. So the crewmen of *Apollo 7* whirled through space suffering from stopped up ears and noses. They took aspirin and decongestant tablets and discussed their symptoms with the doctors.

Several days before the mission ended, they began to worry about wearing their suit helmets during reentry, which would prevent them from blowing their noses. The buildup of pressure might burst their eardrums. Slayton, in mission control, tried to persuade them to wear the helmets, anyway, but Schirra was adamant. They each took a decongestant pill about an hour before reentry and made it through the acceleration zone without any problems with their ears.³⁹

That “magnificent flying machine,” as Cunningham called it, circled the earth for more than 260 hours. On 22 October, the crew brought the ship down in the Atlantic southeast of Bermuda, less than two kilometers from the planned impact point. On landing, the craft turned nose down, but the crew quickly inflated the air bags and the ship righted itself. The tired, but happy, voyagers were picked up by helicopter and deposited on the deck of the U.S.S. *Essex*.⁴⁰

Apollo 7 accomplished what it set out to do—qualifying the command and service module and clearing the way for the proposed lunar-orbit mission to follow. And its activities were of national interest. A special edition

* Producer of the Bill Dana “Jose Jimenez in Orbit” record album in the 1960s and provider of many of the music tapes broadcast to the Gemini crews from mission control.

CHARIOTS FOR APOLLO

of NASA's news clipping collection called "Current News" included front page stories from 32 major newspapers scattered over the length and breadth of the nation. Although the postmission celebrations⁴¹ may not have rivaled those for the first orbital flight of an American, John Glenn in 1962, enthusiasm was high—and this fervor would build to even greater heights each time the lunar landing goal drew one step closer.

THE APOLLO 8 DECISION

Perhaps the most significant point about the lunar-orbit flight proposed for Apollo 8 was that the command and service modules would fly the same route to the moon as for the actual lunar landing. NASA officials realized that this was risky, since Apollo 7 had not yet qualified the spacecraft when their tentative decision was made. And data from that launch, using the Saturn IB, would not help them decide whether the Saturn V could make the lunar mission.⁴²

Phillips formally set the plan into motion in a directive issued on 19 August. Because of Webb's restrictions about waiting until the performance of Apollo 7 was known, earth-orbital objectives were still listed, but crew assignments were shifted and the mission was moved forward one flight. That same day, NASA publicly announced the flight as an expansion of Apollo 7, although agency spokesmen said that the exact content of the mission had not been decided.⁴³

CSM-103 arrived at the Cape in mid-August, and testing began. Some modifications were necessary but, in most cases, no hardware changes that might cause delays were acceptable. Mueller kept Paine informed of the status, noting in detail how many days the work schedule lagged and why. These holdups were usually minor, although Hurricane Gladys did cause an additional two-day delay.⁴⁴

Paine was still concerned about manning the Saturn V, because of the pogo problem. Phillips told him that the Apollo leaders had decided, about two weeks after *Apollo 6*, to plan for a manned flight but to revert to unmanned, if necessary. Paine also questioned the reliability of the service propulsion module. Mueller reviewed its test history and reported that a complete flight system of the "present configuration" had never failed to fire. Of all configurations, only 4 firings had failed in 3200 attempts, and Mueller assured Paine that none of the problems encountered were characteristic of the present engine.⁴⁵

During a session of Mueller's Certification Board in Huntsville on 19 September, the Saturn V was given a clean bill of health, and the members agreed that the launch vehicle was no longer a constraint to manned flight. In the meantime, Huntsville and Houston had worked out an agreement on

payload weight. The load for Saturn 503 was set at 39 800 kilograms, including 9000 kilograms for the lunar module test article. (A fully fueled production lander, scheduled for subsequent missions, would weigh 14 500 kilograms.)⁴⁶

On 7 November, the Certification Board looked at all parts of Apollo 8—spacecraft, launch vehicle, launch complex, mission control network, and spacesuits. A C-Prime Crew Safety Review Board had already studied these items for Phillips and had “concluded that the Apollo 8 Space Vehicle is safe for manned flight.” Mueller’s board concurred.⁴⁷ Now it was up to Paine and the Apollo executives to decide whether Apollo 8 would fly to the moon.

At the Apollo executives meeting on 10 November, Phillips summarized the lunar-orbit proposal, James discussed launch vehicle status, Low gave spacecraft status, Kraft talked about flight operations, Slayton outlined the flight plan, and Petrone reported that the Cape could be ready by 10 December, although there would not be a lunar launch window until the 21st. Phillips said he recommended that NASA go for lunar-orbit. Mueller then asked Low and Phillips to list the things that were absolutely essential for a safe round trip. The program leaders replied that the service propulsion system had to work, to get the spacecraft out of lunar orbit, and there had to be at least 60 hours of oxygen remaining to get the crew back to earth. Redundancies could support the environmental system, barring a major break of the main structure; and the fuel cells could handle the power demands with only one of the three working—unless, of course, there was a complete electrical short. There were risks, yes, but these risks would be there on all missions; there was no way to ensure perfect safety.

Next, Mueller asked for the views of the attending Apollo executives.

Walter F. Burke (McDonnell Douglas): The S-IVB can do any of the missions described, but I favor circumlunar rather than lunar orbit since there has been only one manned CSM.

Hilliard Paige (General Electric): The checkout equipment is doing the same thing it has done before; there are no reservations from a reliability standpoint; and NASA should go, and is ready to go, into lunar orbit.

B. P. Blasingame (AC Electronics): We have carefully examined the guidance equipment and consider it ready for a lunar orbit mission. It is the right size step.

Stark Draper (MIT): No reservations.

B. O. Evans (IBM): Go.

R. W. Hubner (IBM): The instrument unit is ready.

George M. Bunker (Martin Marietta): The presentation here today makes a persuasive case. Go for lunar orbit.

T. A. Wilson (Boeing): We have confidence in the hardware. It is right to go for lunar orbit.

Leland Atwood (North American): This is what we came to the party for.

CHARIOTS FOR APOLLO

Robert E. Hunter (Philco-Ford): We have no reservations about being able to support the complete mission.

Thomas F. Morrow (Chrysler): We have no hardware on this mission and perhaps can be even more objective. I believe we should go for lunar orbit, but the public should be aware that there are risks.

William P. Gwinn (United Aircraft): I am impressed by the pros and cons of risk, but I believe General Phillips' recommendation is the right one.

Joseph Gavin (Grumman): We also have no hardware on this mission (except a test article), but the design of the mission makes a lot of sense—it is one we should do.

William Bergen (North American): I agree with Morrow that lunar orbit has more risk. It is questionable if we will get, and can expect, the same high degree of performance from systems as we got on Apollo 7, but a repeat flight is a risk with no gain.

G. H. Stoner (Boeing): I endorse the recommendation without reservation.

Gerald T. Smiley (General Electric): Morale is now high; less than lunar orbit would impact this morale.⁴⁸

Thus on 10 November a second group voted yes on the proposition to send man on his first flight to the vicinity of the moon.

The next day, Mueller told Paine he had discussed the proposal with the Science and Technology Advisory Committee and the President's Science Advisory Committee and both of these prestigious groups favored the mission. The manned space flight chief said he also agreed "that NASA should undertake a lunar orbit mission as its next step toward manned lunar landing."

Paine listened to presentations by Phillips, James, Low, Kraft, and Petrone on 11 November. The same day, Paine asked Gerald Truszynski if the tracking network would be ready and Lieutenant General Vincent G. Huston if the Department of Defense could support the mission. He called in key members of his staff and the directors of the three manned space flight centers for their statements. The acting administrator also telephoned Frank Borman and learned that the astronauts supported the mission wholeheartedly. Paine then approved Phillips' recommendation. Phillips wired the field centers to be ready for a lunar-orbit flight on 21 December.⁴⁹ NASA had crossed another Rubicon in its decision-making—a historic one.

Apollo 8: THE FIRST LUNAR VOYAGE

Invitations had been issued to watch departures before, but not for a trip like this one. For the first time, man would ride atop a Saturn V launch vehicle. And before he returned to the earth, he would travel in a region where the gravitational pull of another celestial body was stronger than that

*You are cordially invited to attend
the departure of the
United States Spaceship Apollo VIII
on its voyage around the moon,
departing from Launch Complex 39A, Kennedy Space Center,
with the launch window commencing at
seven a.m. on December 21, 1968*

r.s.v.p.

The Apollo VIII Crew

of his home planet—a first in history that would endure no matter where mankind might go in the future.

As soon as Borman's crew learned, on 10 August, that it might fly a lunar mission, the men began to train for the moon flight. On 9 September, sessions on the Cape simulator began. Six weeks before launch, these turned into day-after-day, ten-hour work periods. With the help of the support team—Mattingly, Carr, and Brand, who followed the hardware, coordinated the preparation of checklists, and worked out spacecraft stowage—the crew was ready on time. Shortly after 2:30 on the morning of 21 December, Borman, Lovell, and Anders rose and dressed for the launch day breakfast with, among others, George Low, the man who had hatched this scheme to send them into lunar orbit on Apollo's second manned flight.⁵⁰

Many guests were in Florida for the send-off, thousands more than the crew had formally invited. In the chilly predawn, the visitors clogged the roads, their headlights flashing, searching for the best vantage points. Busloads of newsmen trundled through the gates, heading for the press area, and helicopter-borne groups of VIPs landed near the special viewing stand. All attention focused on Apollo 8, bathed in the glare of spotlights that made it visible for many kilometers. Radio announcers, television commentators, and public address spokesmen told millions around the world and the thousands in the Cape area that soon three astronauts would leave this globe to visit another. At 7:51, Borman, Lovell, and Anders, lying in their couches 100 meters above the launch pad, started on that journey.⁵¹

Riding the huge Saturn V, propelled by more power than man had ever felt pushing him before (33.4 million newtons, or 7.5 million pounds of thrust), the crew had varied impressions. Borman thought it was a lot like riding the Gemini Titan II. Lovell agreed but added that it seemed to slow down after it left the pad. Rookie astronaut Anders likened it to "an

CHARIOTS FOR APOLLO

old freight train going down a bad track." The S-IC stage shook the crew up, but not intolerably. Despite all the power, the acceleration reached only four g. At engine cutoff, it dropped to one g. During S-II stage acceleration, pogo stayed within allowable limits and caused no pain to the pilots. They were glad, however, when the engines cut off and the second stage fell away. A dozen minutes after launch, the S-IVB third stage had already fired to drive itself and the spacecraft into earth-orbital flight. Borman, Lovell, Anders, and the flight controllers checked the spacecraft and third stage systems for a revolution and a half, in preparation for the next step in the mission. At 10:17, former crew member Collins—back from his bout with the bone spur and now at the capcom's console rather than in the center couch of *Apollo 8*—opened a new era in space flight when he said, "All right, you are go for TLI [translunar injection]." Many watchers in Hawaii, who had seen a launch on live television for the first time, raced outside and looked for the fireworks high above them.⁵²

For five minutes, the S-IVB fired, increasing its speed from 7600 to 10 800 meters per second. Borman, Lovell, and Anders now traveled at a greater speed than any human being ever had, shooting outward fast enough to escape the earth's gravitational influence. Asked later about impressions at translunar injection, Borman replied:

Psychologically it was a far easier flight than Gemini 7. You adopt a philosophical approach after you burn TLI, and I wasn't really concerned about anything. When you are in earth orbit you are always aware that if something happens you have to react quickly to get down. Once you burn TLI, . . . you really are not concerned with reacting swiftly because it is going to take you [at least] two or three days to get home anyway.

The command and service modules separated from the S-IVB and flipped around so the crew could photograph the adapter, where the lunar module would be housed on future voyages. Borman commented that formation flying was no more difficult with the S-IVB than it had been with the Gemini Agena and that docking with the LM should pose no problems. Since they had no lander on this mission, they chose not to get too close to the S-IVB. The crew used the small reaction control engines on the service module to begin a separation maneuver with a velocity change of less than a meter per second. But Borman soon noted that the S-IVB was getting closer, instead of moving away. Both the crew and the flight controllers were puzzled. Communications crackled back and forth. Kraft and Bill Tindall talked with Carl R. Huss, who was manning the mission planning and analysis desk in the flight support area, demanding to know what to do. Huss held them off until his group had time to figure out that the crew had not made its maneuver exactly as it should. Studying the relative positions of the two vehicles, Huss soon gave the controllers new information to

radio to the space ship. The crew fired the small engines again—this time for a change of two meters per second, changing the trajectory and moving away from the too-friendly third stage.⁵³

Early in the flight, the crew was captivated by the view of the earth from space, especially the detail revealed at a single glance. Borman commented, "We see the earth now, almost as a disk." Then he asked Collins to "tell Conrad he lost his record." Conrad and Gordon had been the high-flight champions of Gemini. Lovell, looking through the center window, began to call out place names as if he were an announcer in a railway terminal: Florida, Cuba, Gibraltar, Africa (East and West), Central America, and South America. Borman suggested that Collins warn "the people in Tierra del Fuego to put on their rain coats; looks like a storm . . . out there."⁵⁴

A safe distance away from the S-IVB, the three crewmen left their couches to take off their pressure suits and met with a surprise—motion sickness. Rapid body movements brought on nausea. Borman suffered the most. There had been a rash of gastroenteritis cases at the Cape just before launch. This "24-hour intestinal flu" might have caused Borman's illness, but there was another possibility. Because it had taken longer to get away from the S-IVB than had been planned, he was late getting to his rest period. To make sure he went to sleep quickly, he had taken a Seconal tablet. During preflight testing of the medical supplies Borman had a slight reaction to this sleep-inducing pill, so he blamed the medication for at least part of his distress. When he awakened, after very fitful rest, Borman retched and vomited twice and had a loose bowel movement. The waste management system worked, but just barely. The crew reported their problems to the flight surgeon and, as Collins said later in *Carrying the Fire*, "the first humans to leave the cradle had called for their pediatrician." Next day, however, Borman happily told flight control, "Nobody is sick."⁵⁵

For the first six hours of flight, the round hatch window through which Lovell watched the earth receding had been clear. Then it had clouded over until it was almost useless. The clouding was caused, as it had been during Schirra's flight, by a gas from the silicone oils used in a sealant compound. The two side windows also fogged over, but to a smaller degree. Only the rendezvous windows remained clear throughout the mission. On one occasion crew members complained that pictures of the sun taken through the side windows would be of little value, and they could not even see the sun through the rendezvous windows. They could not see the moon through *any* of the windows. Navigator Lovell later recalled that

we never really saw the moon. It was a crescent moon, and most of it was dark. I saw it several times in the optics as I was doing some sightings. By and large the body that we were rendezvousing with, that was coming from

CHARIOTS FOR APOLLO

one direction as we were going to another, we never saw. And we took it on faith that the moon would be there, which says quite a bit for Ground Control.⁵⁶

At a distance of 223 000 kilometers from the earth, 31 hours after leaving home and 40 before reaching the moon, the crew put on its first television show. Scenes showed the inside of the craft, with Borman as director and narrator, Lovell as actor (preparing a meal), and all three crewmen as cameramen. Anders installed a telephoto lens to get a better view of the earth, but the lens did not work. When the crew switched back to the interior lens, the earth looked like a white blob. Lovell pointed out that the earth was very bright and they were using a low-level lens. Borman added that the camera was pointing through a hazy window. He was disappointed that they could not show their viewers the "beautiful, beautiful view, with [a predominantly] blue background and just huge covers of white clouds."⁵⁷

A hundred thousand kilometers farther out and a day later, the crew again unstowed the television camera. This time the telephoto lens worked better. Lovell described what the audience was seeing: the Western Hemisphere was clearly in view and again he called out names—the North Pole, South America all the way down to Cape Horn, Baja California, and the southwestern part of the United States. Once, in a thoughtful vein, he turned to his commander:

Frank, what I keep imagining is if I am some lonely traveler from another planet what I would think about the earth at this altitude, whether I think it would be inhabited or not. . . . I was just curious if I would land on the blue or brown part of the earth.

Anders interjected, "You better hope that we land on the blue part."⁵⁸

Following the second video presentation, the crew neared a new stage in manned space flight—travel to a place where the pull of earth's gravity was less than that of another body. At 3:29 in the afternoon on Monday, 23 December, that historic crossing was made. At that point, the spacecraft was 326 400 kilometers from the earth and 62 600 from the moon, and its velocity had slowed to 1218 meters per second. Gradually, as the ship moved farther into the moon's gravitational field, it picked up speed.⁵⁹

Now the crew prepared for another event—again denoted by one of the abbreviations with which space flight jargon abounds, LOI (lunar-orbit insertion). Since the craft was on a free-return trajectory—a path shaped like a figure eight that would loop the ship around the back of the moon and return it to the earth—Borman wanted "a perfect spacecraft before we can consider the LOI burn." He would hate to leave that good trajectory and then find out that something was wrong. So far, the big service module engine had worked perfectly every time, but the path to the moon had been

so precise that only two of four planned midcourse firings had been necessary. Ground control assured him that everything was in order. At 68 hours 4 minutes into the mission Carr, at the console, told the crew, "You are go for LOI." He also informed the astronauts that the closest point of their approach should be 119 kilometers above the moon. Minutes before this transmission, when Borman commented that they still had not seen the moon, Carr asked what they could see. Anders replied, "Nothing. It's like being on the inside of a submarine."⁶⁰

During Mercury, Gemini, and Apollo orbital missions, there had been periods of communications silence, especially in the southern hemisphere, because the worldwide tracking network did not cover all areas. Up till now Borman and his crew had been in continuous contact during the translunar voyage, but no communications would be possible when the spacecraft went behind the moon. Just before loss of signal in the early hours of 24 December (at 4:49), Carr wished them a safe journey, and Lovell answered, "We'll see you on the other side." Eleven minutes later, traveling at 2600 meters per second with their heads down so they could watch the lunar landscape, they fired the service module engine for four minutes to reduce their speed by 915 meters per second and get into an orbit approximately 111 by 312 kilometers. Although the engine performed flawlessly, Lovell called it the "longest four minutes I ever spent." While the engine was firing, Lovell and Anders exclaimed about their fantastic view of the moon. Anders added that he had trouble telling the holes from the bumps. Borman called them back to watch their dials.⁶¹

Borman, Lovell, and Anders knew that the engine had fired successfully, but nearly a billion persons in 64 countries (according to *TV Guide*) did not. If the spacecraft had not gone into orbit, it would come back into communications range 10 minutes earlier than planned. After what seemed an interminable wait, Paul Haney, on the public information console in flight control, gleefully announced, "We got it! We've got it! Apollo 8 now in lunar orbit."⁶²

After 15 minutes of describing the first engine firing and getting numbers for the second firing (to circularize the orbit at 112 kilometers above the lunar surface), the crew members told their fellow men what the moon looked like at this close range. Lovell said:

Okay, Houston, The moon is essentially gray, no color; looks like plaster of Paris or sort of a grayish deep sand. We can see quite a bit of detail. The Sea of Fertility doesn't stand out as well here as it does back on earth. There's not as much contrast between that and the surrounding craters. The craters are all rounded off. There's quite a few of them; some of them are newer. Many of them . . . —especially the round ones—look like hits by meteorites or projectiles of some sort.

CHARIOTS FOR APOLLO

(Later, during the technical debriefings, Lovell added that

the Lunar Orbiter photographs which we had on board were quite adequate. There was no problem at all in determining objects particularly on the near side of the moon. There are suitable landing sites. They are very easily distinguished. We could pick them up. We could work our way in. . . . The Lunar Orbiter photos again were helpful . . . to check the craters on the back side.)

After looking at the back of the moon on several orbits, Anders was moved to comment:

It certainly looks like we're picking the more interesting places on the moon to land in. The backside looks like a sand pile my kids have been playing in for a long time. It's all beat up, no definition. Just a lot of bumps and holes.⁶³

As *Apollo 8* whirled around the moon on its ten two-hour circuits, the spacecraft location display seemed odd at first to those watching the map in mission control. In earth orbit, spacecraft had always gone from left to right on the display panels; on the lunar charts, however, this vehicle moved from right to left. And while it traveled the crew continued to talk about the view. Anders expressed the general opinion that the moon was an "unappetizing looking place"; nevertheless, it did have a kind of stark beauty. Astronauts commented on the hues of light and dark caused by earthshine and sunshine. They gave temporary names to some of the craters: names like (Harrison) Schmitt, (George) Low, (Robert) Gilruth, (Joseph) Shea, (Theodore) Freeman, (Gus) Grissom, (Ed) White, (James) Webb, (Thomas) Paine, (Elliot) See, (Alan) Shepard, (Donald) Slayton, (Samuel) Phillips, (Christopher) Kraft, (Roger) Chaffee, (Charles) Bassett, and (Gerald) Carr. Once, when flight controller John W. Aaron was the only one to notice in the general excitement that the environmental system needed an adjustment, Crater Aaron was named on the spot.⁶⁴

NASA had been asked by some to postpone the December lunar-orbiting mission, lest some accident mar Christmas celebrations on earth. But now, as *Apollo 8* circled the moon this Christmas Eve, there was additional rejoicing. Early in December, Borman and a friend had selected a prayer for the occasion. During the third lunar revolution, Borman asked, "Is Rod Rose there? I have a message for him," and sent the following transmission:

To Rod Rose and the people of St. Christopher's, actually to people everywhere—

Give us, O God, the vision which can see thy love in the world in spite of human failure.

TASTES OF TRIUMPH

Give us the faith to trust thy goodness in spite of our ignorance and weakness.

Give us the knowledge that we may continue to pray with understanding hearts.

And show us what each one of us can do to set forward the coming of the day of universal peace. Amen.

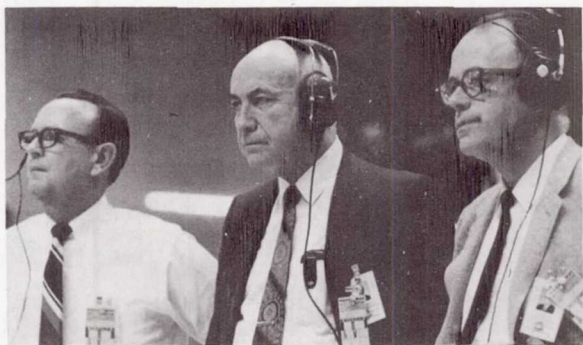
The crew members had consulted other friends about a possible theme for their mission, something to signify one world, something to tell everyone on earth. One suggestion was that they read the story of the Creation in the first 10 verses of the Book of Genesis in the Bible. This they did, during the ninth revolution, closing with "Good night, good luck, a Merry Christmas and God bless all of you—all of you on the good earth."⁶⁵

Borman later admitted that he and his crew had not really wanted to carry a television camera; fortunately the decision had not been left to them. Television from the moon had a wide audience. During the flight the crew was told that its shows were being seen all over Europe, even in Moscow and East Berlin; in Japan; in North, Central, and South America; and perhaps in Africa. Lovell, using his optical devices to get a better look, described what was being photographed. Anders raced from window to window for the best vantage points for photographing the lunar surface, especially the areas being considered for landing sites. By the seventh revolution, both of them were so tired that Borman put a stop to the observations. Soon, he knew, they had to start thinking about transearth injection (TEI, another of those important abbreviations)—entrance on the path for home.⁶⁶

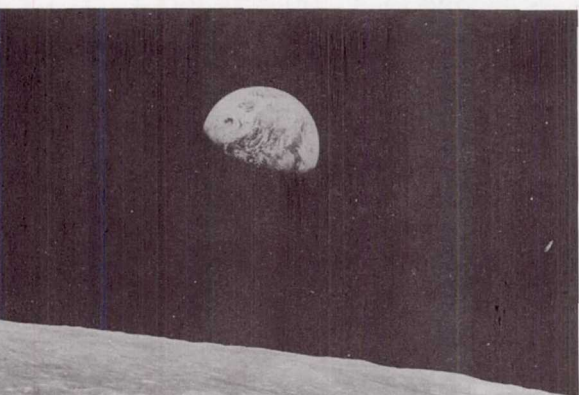
On the tenth lap of the moon, on Christmas morning, 3 days, 17 hours, and 17 seconds after earth launch, the service module engine fired to increase their speed by 1070 meters per second. Rounding the corner from the back of the moon, Lovell told Mattingly, who had taken over as CapCom for that shift, "Please be informed there is a Santa Claus." In mission control, the holiday became a truly festive occasion. A Christmas tree was placed below the flight status board, which again showed an earth map with red and green lights, the traditional colors of the season. Schmitt, who had coached the crew for its geological observations, read a parody on Clement C. Moore's poem, "T'was the Night before Christmas."⁶⁷

After leaving the moon, the crew was worn out. The astronauts rested, letting "Isaac Newton" do most of the driving. Following their naps, CapCom Carr gave them the latest earth news, with emphasis on the impact their voyage had made on the world.⁶⁸ On the whole, *Apollo 8's* explorations in December 1968 were acclaimed enthusiastically by the multitudes who looked at their world for the first time from thousands of kilometers in space and at their moon from slightly more than a hundred.

The trip back to the earth was uneventful. During the entire trip, CSM-103 registered only such expected irregularities as fogging windows,



Apollo 8 carries the first men beyond the pull of the earth, to circle the moon, 21–27 December 1968. At left, three top Manned Spacecraft Center officials—Christopher Kraft, Robert Gilruth, and George Trimble (left to right)—wait to hear that the spacecraft has been launched.



Earthrise on the lunar horizon greets the Apollo 8 crew coming from behind the moon after lunar orbit insertion.



The crew caught a nearly circular moon in the photo above. The edge of the Sea of Tranquility is on the left, southwest of and close to the circular Sea of Crisis (Mare Crisium). Borman, Lovell, and Anders were the first men to see the back of the moon (left). Among prominent features are Mare Smythii, Mare Crisium, Mare Fecunditatis, Mare Nectaris, Cyater Langrenus, and several rayed craters.

TASTES OF TRIUMPH

puddling water, and clattering cabin fans. Now the space-weary travelers could rest, eat, sleep, show television, and enjoy the ride home. Lovell continued his navigational sightings, and flight control did the tracking. Neither could find more than a minor error in the course hours before the scheduled splashdown in the Pacific; one correction (of less than two meters per second) was made. Early Saturday morning, 14 500 kilometers above the earth, the crew fired the pyrotechnics to separate the command module from the service module, which had worked perfectly whenever it was needed. Fifteen minutes later, the spacecraft crossed into the fringes of the atmosphere, 120 kilometers above the earth. Borman told Mattingly they had a real fireball but were in good shape. Spacecraft speed increased to 9700 meters per second, subjecting the crew to a load of nearly seven g.

The craft flew an entry curve to a point over northeast China, slanted to the southeast, and landed on target in the mid-Pacific. So accurate was the landing that it worried one of the chief mission planners and data watchers in Houston. Bill Tindall wrote to Jerome B. Hammack, head of the Landing and Recovery Division:

Jerry, I've done a lot of joking about the spacecraft hitting the aircraft carrier, but the more I think about it the less I feel it is a joke. There are reports that the C Prime command module came down right over the aircraft carrier [stationed at $165^{\circ}02.1'$ west longitude and $8^{\circ}09.3'$ north latitude] and drifted on its chutes to land [at $165^{\circ}01.02'$ west and $8^{\circ}07.5'$ north, only 4572 meters] away. This really strikes me as being too close. . . . The consequence of the spacecraft hitting the carrier is truly catastrophic. . . . I seriously recommend relocating the recovery force at least [8 to 16 kilometers] from the target point.



At right, three jubilant astronauts—Lovell, Borman, and Anders (left to right)—back on the earth after their Apollo 8 mission, tell what they saw.

Astronauts Gerald Carr, Donald Slayton, Neil Armstrong (seated left to right in the left photo), and Harrison Schmitt and Edwin Aldrin (standing) compare mosaics of Lunar Orbiter photographs with scenes televised from the moon to Mission Control by Apollo 8 crewmen.



CHARIOTS FOR APOLLO

The craft came down in darkness on Friday, 27 December (6 days, 3 hours, and 42 seconds after launch), flipping over on its nose as it landed. Until Borman punched the button that inflated the air bags to upright the spacecraft, its flashing light beacon was lost to the sight of the recovery helicopters. Mission ground rules required a daylight recovery, so Borman and his crew waited 45 minutes for the swimmers to open the hatches. A few minutes later, the helicopter deposited the crew on the deck of the U.S.S. *Yorktown* for the last lap of—in Borman's words—"a most fantastic voyage."⁶⁹

Nineteen hundred and sixty-eight was a banner year for the United States space program, and the celebrations for the latest space explorers were enthusiastic. In Washington on 9 January 1969, Borman, Lovell, and Anders visited the White House, where President Johnson presented them with NASA's Distinguished Service Medal. Then their motorcade passed through cheering crowds on its way to Capitol Hill, where a joint session of Congress and the Supreme Court heard Borman's report. The theme of his talk was that *Apollo 8* "was a triumph of all mankind." The three astronauts went to the Department of State auditorium for a press conference, to describe their trip and answer questions from the news media. New York City welcomed them with a ticker-tape parade on the 10th of January, Newark hailed them on the 11th, and Miami greeted them on the 12th during the Super Bowl football game. They returned to Houston on the 13th for a hometown parade. Incoming President Richard M. Nixon sent Borman and his family on an eight-nation goodwill tour of western Europe; they visited London, Paris, Brussels, The Hague, Bonn, Berlin, Rome, Madrid, and Lisbon. Everywhere they went, the moon travelers depicted the earth as a spaceship and stressed international cooperation in space.⁷⁰

Now, 1969—the year President Kennedy had set for meeting his challenge—was here. North American's command and service modules had proved that they were ready to achieve that goal. It was time for Grumman's lunar module to be put through some strenuous rehearsals to prepare it for the last—and perhaps the most difficult—100 kilometers of the 380 000-kilometer voyage.

12

The Trailblazers

1969: First Half

Apollo's successes in the seventh and eighth missions augured well for a manned landing on the moon during 1969. But program executives were not complaisant about even these demonstrations of the command and service modules and the Saturn V. Nor did they exhibit any tendency to depart from a systematic step-by-step plan and to stampede toward a lunar landing earlier than scheduled, although President Kennedy's deadline year had arrived.

Frank Borman's *Apollo 8* crew in its flight near the moon had met no major obstacles, but the need for trailblazing missions had not lessened. Associate Administrator for Manned Space Flight George Mueller in Washington wrote Center Director Robert Gilruth in Houston after *Apollo 8* to remind him, "It is essential that we not rest on our laurels, for we have yet to land on the moon." Gilruth foresaw few chances for resting. Only three days of the new year had passed when John D. Stevenson, Director of Mission Operations in Washington, projected five Apollo flights for 1969, with launches on 28 February, 17 May, 15 July, 12 September, and 10 December. This schedule was essentially the same race-with-the-decade timetable outlined a year earlier.¹

SCHEDULES AND LINGERING WORRIES

NASA had scheduled six missions in 1968 but had found only four necessary (see Chapters 10 and 11). The agency could also omit a flight in 1969, if the crew of the G mission listed for 15 July could touch down,

CHARIOTS FOR APOLLO

stay awhile, and leave the moon safely. The intervals between following launches might then be as long as six months to assimilate more of what had been learned before going on to the next mission. But until the first landing took place, Mueller and his management council still planned to launch a mission every two and a half months.²

NASA Headquarters continued to emphasize schedules, even while worrying lest something be overlooked in meeting the deadline. To avert this possibility, Washington kept adding specialized administrative layers, and Gilruth shortly complained to Mueller that too many Headquarters review teams were investigating one thing or another about the mission.³ In addition to administrative actions, two technical suggestions surfaced at Headquarters. The first, tinged with conservatism, was to land an unmanned lunar module on the moon before a manned vehicle touched down. Mueller told Acting Administrator Thomas Paine that modifying the lander for unmanned flight would take too long and would, in the end, give very little in return for the costs in time and money. The second idea, proposed by Apollo Program Director Samuel Phillips, was to ship the command and service modules to the Cape already assembled and mated, rather than separately. Houston's Apollo Spacecraft Program Manager George Low informed Phillips it would save time at Kennedy but would add time at Downey. It would also cost an extra million dollars.⁴

Good reasoning lay behind this paradox of both hurrying and holding back. Ever-present desk and wall calendars kept reminding the managers that time was running out, yet they had to guard against another terrible tragedy in the program. Two areas, however, were viewed with satisfaction—program costs and spacecraft weights. Both North American and Grumman were operating within fiscal 1969 financial limits. And, although fire-related changes in the command and service modules had increased the weight significantly, NASA and North American had reversed this trend in the latter half of 1967. In the succeeding months, the command module's bulk had actually been whittled down. Lunar module weight, however, did not stabilize until mid-1968, and that machine still had some lingering technical troubles.⁵

One of the more exasperating problems was the electrical wiring in LM-3. Kennedy Space Center engineers had complained about the vehicle ever since its arrival in Florida in June 1968. In late January 1969, Low asked Martin L. Raines, reliability and quality assurance chief in Houston, to find out just how bad the wiring was. Raines told the Apollo manager that he had found hundreds of splices in the vehicle, but it could still fly safely. Most of the broken wiring, Raines said, was caused by the low tensile strength of the annealed copper wire. The wiring in LM-4, ticketed for Apollo 10, should cause fewer problems, since a high-strength copper alloy would be used.⁶

Another recurring lander ailment was stress corrosion, or metal crack-

ing. Grumman had no structural failures during testing, but the cracks worried both NASA and contractor engineers. A number of fittings were replaced in LMs 3, 4, and 5; by the end of January 1969, the vehicles for Apollo 9 and 10 were considered ready for launching. If problems arose later, more fittings could be changed on LM-5 as it passed through its testing program.⁷

Operational as well as component problems raised some issues during this period. For example, what would happen to the electrical systems in the spacecraft when the two vehicles docked? Ground tests at Downey and the Cape revealed that there would be little electromagnetic interference. A larger question centered on flying the lunar module after the vehicles separated. About a year before the Apollo 9 mission, astronaut Charles Conrad had commented to Bill Tindall, a leading Houston mission planner, that the lander would be hard to handle when a large amount of the propellant had been used and the descent stage had been dropped off. At a flight program review in October 1968, Phillips asked about the problems of steering the lightweight ascent stage manually. Gilruth directed Warren J. North and Donald C. Cheatham to find out what the difficulties would be. North and Cheatham reported that docking would require precise control but that this and other guidance tasks had been successfully simulated at Bethpage, in Houston, and at Langley.⁸

Perhaps the biggest concern before Apollo 9 was the docking maneuver. A 1972 report revealed that there was little confidence in the docking system in early 1969. At a January program review, Phillips said that problems encountered during probe and drogue testing worried him. On several occasions, when the command module's extendable probe had nuzzled into the lander's funnel-shaped drogue, the capture latches had failed to engage. In other tests, they had only partially caught, raising the specter of "jack-knifing" and possible damage to one of the spacecraft, probably the lunar module. Phillips was also concerned that the sharp edges on the probe might scar the drogue when the craft were reeled together and prevent airtight sealing of the 12 latches on the command module docking ring. Low asked his deputy, Kenneth Kleinknecht, to investigate. On 14 January, Kleinknecht and six others* from the Manned Spacecraft Center went to Downey to see what was being done about correcting 17 known problem areas. North American personnel responded to each criticism to the satisfaction of the team.⁹

Although the spacecraft occupied the center ring of concern, Marshall Space Flight Center focused on a nagging item a little lower in the stack.

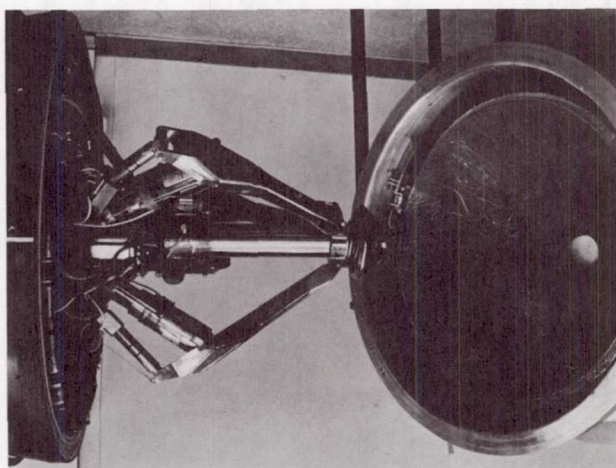
* The team members were Maxime A. Faget, Engineering and Development; Joseph N. Kotanchik, Structures and Mechanics; Christopher C. Kraft, Jr., Flight Operations; Raines, Reliability and Quality Assurance; Donald K. Slayton, Flight Crew Operations; and Harmon L. Brendle (secretary), the Apollo Spacecraft Program Office.

CHARIOTS FOR APOLLO

Borman and his crew aboard *Apollo 8* had been grateful when the second (S-II) stage of the Saturn V finished thrusting and dropped away. Although the launch had been neither particularly painful nor dangerous, it had shaken them up and bounced them about. Launch vehicle engineers concluded that the shaking had been a form of pogo, since the pulsing engines had increased the vibrations. The Marshall and Rocketdyne troops pounced on the problem, trying out various fuel-feeding combinations through the propellant valve. Another suggested cure was to increase the pressure to the inlet of the oxidizer pump. Time was too short for tests of this method before the scheduled launch, and there were some objections; but the managers decided to raise the pressure in the propellant tanks a little and hope for the best. The crew on *Apollo 9* might very well encounter just as much pogo as the crew of the preceding flight, but that was not enough to delay the launch.¹⁰

A DOUBLE WORKLOAD

Apollo 9 gave the Kennedy launch preparations team its first opportunity to simulate the launch of a lunar landing mission all the way through liftoff. (*Apollo 8*, with only the command and service modules aboard, represented just half the spacecraft preparation task.) This time—in addition to checking, stacking, and rechecking the multistage Saturn V—the team had to get two spacecraft ready for flight and launch them. The beehive of activities, employing thousands of persons, grew more frenzied as hardware for several missions began arriving regularly from the factories. For example, before *Apollo 8* left its launch pad on 21 December 1968, all the pieces of *Apollo 9* and some of the parts for *Apollo 10* were already in Florida.



Spacecraft docking devices: the command module probe and docking ring at left; the lunar module drogue at right.

LM-3 arrived from Bethpage in June 1968. By the end of September four altitude chamber tests of the ascent stage had been run, to check the environmental control system and the operation of many components under simulated vacuum conditions of space. During this time, engineers and technicians examining the descent stage found dimples (small depressions formed during welding) in the oxidizer lines. Since the dents were within accepted limits, they caused no problems. Elsewhere, other workers were stacking the S-II stage on top of the S-IC in the huge Vehicle Assembly Building.¹¹

The ascent and descent stages of the lander were then joined, tested, and taken apart again. When inspectors found cracks in the ascent stage engine, a heavier engine was substituted. The command module and the service module arrived from Downey the first week in October, and the North American Cape team, even with all its experience, had trouble fitting them together. When the attitude-control-thruster quad sets were attached to the service module, a cracked quad was found. While that was being evaluated, the command module and the lunar module were brought together for a docking test. The command module was then moved to the altitude chamber for tests similar to those the lunar module had undergone, and the lander was hauled into a hangar for the installation of such components as the rendezvous radar, antennas, and pyrotechnics. From time to time, the command and service modules, the lunar module, or the launch vehicle were either a few days ahead of or behind the schedule. In mid-December, however, Mueller told Paine that all vehicles were on time.¹²

On 3 January, the big stacked vehicle lumbered on its carrier out of the assembly building and crawled toward Launch Complex 39. While flight simulations, linked with the control center in Houston, and all the normal jobs at the pad—cabin leak checks, electrical power tests, and component operations, among others—were going on, some engineers were working on technical problems that had cropped up during previous missions. One was the fogging spacecraft windows, particularly the round one in the hatch door. Samples of contaminants from CSM-101 and CSM-103 were studied, and the hatch window from 101 was tested by subjecting it to the hot and cold extremes met in space. Some thought a better method for curing the glass might eliminate the fogging, but others, analyzing the residue from thruster firings, were not at all sure that the space environment was the problem. If firings from the reaction control thrusters (which steered the spacecraft) were smudging the windows, there might never be a solution.¹³

As the work progressed, the accumulated information was fed into the management reviews. The certification review, which covered all flight hardware (including suits), was held at NASA Headquarters on 7 January. Flight readiness reviews were later conducted for each of the vehicles—com-

CHARIOTS FOR APOLLO

mand and service modules, lunar module, and Saturn V—and then confirmed before Apollo Director Phillips. On 28 February, all hardware problems had been solved, all questions answered. Everything was ready for flight—except the pilots. All three astronauts had head colds.*¹⁴

THE MISSION AND THE MEN

When James McDivitt, David Scott, and Russell Schweickart had received their Apollo flight assignment in late 1968, they were faced with an even more complicated mission than the one they contemplated in early 1969. Inspired by the *Gemini VII* and *VI* rendezvous mission in October 1965, when one spacecraft was launched to catch up with another that had been sent into space a dozen days earlier, some NASA officials wanted to use this concept to check out lunar module and command module docking operations in earth orbit. Most Apollo mission planners wanted to avoid the extra tasks required for launching each vehicle on separate Saturn IB boosters, and by 1969 the big Saturn V rocket was all set to boost both spacecraft into earth orbit in a single launch. Although McDivitt and his crew would not have to search for the lunar module in the vastness of space for the rendezvous, this was almost the only thing that made it an easier mission.

From the perspective of early 1969, the manned shakedown cruise of the lunar module, even in earth orbit, was a venturesome journey. The thought of mission commander McDivitt and lunar module pilot Schweickart's flying away from the command module in this machine, which could not return to earth through the atmospheric shield, was a little frightening. In an emergency, however, command module pilot Scott could steer his ship to a rendezvous with a stricken lunar module. NASA officials hoped this would not be necessary; they wanted a smoothly operating lunar module that could simulate many of the steps in the lunar orbit mission.¹⁵

Flight planners had another key objective for Apollo 9: checking out what might almost be called the third spacecraft in the program (a combination of the extravehicular space suit and the portable life support system—the PLSS, or backpack). As a matter of fact, this was the only flight scheduled for the backpack before the lunar landing mission, making it of prime importance in finding out how the equipment worked in the space environment. The commander and the lunar module pilot,

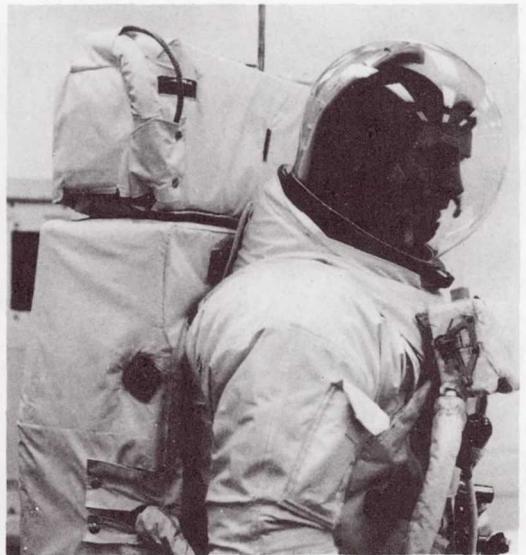
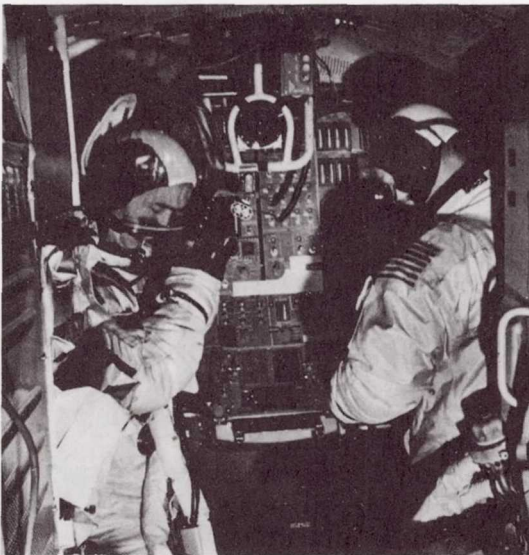
* And this despite elaborate precautions taken to isolate the crewmen and protect them from whatever virus might be making the rounds during the last few days before launch. This launch was the first to be delayed by crew illness. Since the mission simulators had been able to provide training for only the prime crew the last month before Apollo 9 was scheduled for launch, the backup crew was not ready to fly on 28 February.

THE TRAILBLAZERS

wearing their extravehicular garments, would crawl through the tunnel from the command module into the lunar module. Then Schweickart, after donning the backpack and attaching a nylon-cord tether to his suit, would move through the open front hatch and step out on the porch. Finally, he would use handrails to climb over and crawl into the open command module hatch. Schweickart's tasks also included collecting experiment samples on the spacecraft exterior and standing in foot restraints (called "golden slippers") on the lunar module porch to take photographs and operate a television camera.¹⁶

This was a well-seasoned crew. McDivitt, a member of the second group of astronauts, chosen by NASA in September 1962, had been commander of *Gemini IV*, a trailblazer in its own right. It had included what was then considered long-duration flight, a rendezvous experiment, and a highly successful extravehicular exercise. Scott and Schweickart were members of the trainee group picked in October 1963, and Scott had been a crewman on *Gemini VIII* when it made the first docking in space. Although Schweickart had not flown a mission, he had participated heavily in the experiments program and in spacesuit testing. For two years the three men

McDivitt and Schweickart (left to right in left photo) practice in the lunar module simulator for the Apollo 9 mission to evaluate the LM in earth-orbit operations and the Apollo suit in the space environment. Although all three crewmen would be exposed to the space environment, where their lives would depend on their suits, only Schweickart would don the backpack (right photo) that provided independent life-sustaining oxygen and controlled temperature. McDivitt and Scott would draw supplies through umbilical hoses attaching their suits to the spacecraft. Schweickart's backpack is the same model that moon-strolling astronauts would later use.



CHARIOTS FOR APOLLO

had been working as a team. By the time McDivitt's crew was finally ready for flight, it had spent 7 hours in training for each of the 241 hours it would spend in space. At a news conference, McDivitt quipped that he hoped all this training did not imply that the crewmen were slow learners.¹⁷

Because there would be two craft in simultaneous flight, Apollo 9 revived a practice that had been discarded almost four years earlier—call signs, or names, for spacecraft. Gordon Cooper had encountered trouble selling the name *Faith 7* for his *Mercury-Atlas 9* craft to NASA officials. If anything happened, they dreaded the thought of the almost inevitable headline: "The United States lost Faith today." During Gemini, these same leaders had turned down Gus Grissom's selection of "Molly Brown" for *Gemini-Titan 3*, which alluded to both the unsinkable characteristics of an American heroine and the loss of his *Liberty Bell 7* during Mercury. His second choice, "Titanic," was equally unwelcome. After that, missions were simply called by the program name and a number: *Gemini IV*, *Apollo 7*. But a single designation, such as "Apollo 9," was no longer enough. Flight control would have to talk to McDivitt and Schweickart in the lunar module, as well as Scott in the command module. McDivitt's crew named the lander "Spider," for its long thin legs and buglike body. When North American shipped the command module to Florida, its candy-wrapped appearance and shape suggested the tag, "Gumdrop."¹⁸

Apollo 9: EARTH ORBITAL TRIALS

For the 19th flight of American astronauts into space, Vice President Spiro T. Agnew, representing the new administration of Richard Nixon, sat in the firing control room viewing area on 3 March 1969. He and other guests listened to the countdown of the tall Saturn-Apollo structure several kilometers away at the edge of the Florida beach. Fully recovered from their stuffy heads and runny noses, McDivitt, Scott, and Schweickart lay in the mixed-atmosphere cabin of CSM-104. Breathing pure oxygen through the suit system, they tried to adjust an inlet valve that seemed to have two temperature ranges—too hot and too cold. That was their only problem. Less than one second after its scheduled 11:00 a.m. EST liftoff time, *Apollo 9* rumbled upward.¹⁹

In Houston, where more than 200 newsmen had registered to cover the mission, Flight Director Eugene F. Kranz and Mission Director George H. Hage* watched the displays on their consoles while McDivitt and Cap-Com Stuart Roosa called off the events of the launch sequence. There were

* Hage had replaced William Schneider when Schneider was named to head the Apollo Applications Program (later Skylab) after the death of its director, Harold T. Lusk.

the usual vibrations but, on the whole, the Saturn V's S-IC stage gave the crew what McDivitt called "an old lady's ride"—very smooth. The big surprise came when its five engines stopped thrusting. Feeling as if they were being shoved back to the earth, the astronauts lurched forward, almost into the instrument panel. The S-II second stage engines then cut in and pressed them back into the couches. Everything went well until the seven-minute mark, when the old pogo problem popped up again. Although the oscillations were greater than those of Borman's flight, McDivitt's crew lodged no complaints. At 11 minutes 13 seconds from launch, the S-IVB third stage kicked itself and the two spacecraft into orbit 190 kilometers above the earth.²⁰

Upon reaching the orbital station, the trio remembered Borman's warning against jumping out of the couches too quickly and flitting about in the weightless cabin. The men avoided sudden head turns, made slow deliberate movements, took medication—and still felt dizzy. But they were able to go about their duties, checking instruments and extending the docking probe. After more than a circuit, 2 hours 43 minutes into the mission, Scott lit the pyrotechnics that separated the command and service modules from the S-IVB stage and began one of the critical steps in the lunar-orbit concept. He fired the thrusters and pulled the command ship away, turned the ship around, fired again, and drew near what he called the "big fellow." Then he noticed that the command module's nose was out of line with the lander's nose. Scott tried to use a service module thruster to turn left, but that jet was not operating. The crew then flipped some switches, which started the thruster working, and at 3 hours 2 minutes the command module probe nestled into the lunar module drogue, where it was captured and held by the latches.²¹

After docking, McDivitt and Schweickart began preparing for their eventual entry into the lunar module. First, they opened a valve to pressurize the tunnel between the two spacecraft. With Scott reading the checklist aloud, McDivitt and Schweickart removed the command module hatch and checked the 12 latches on the docking ring to verify the seal. Next they connected the electrical umbilical lines that would provide command module power to the lander while the vehicles were docked. McDivitt checked the drogue carefully and found no large scars. Meanwhile, Schweickart glanced out the spacecraft window and failed to see the lunar module in the darkness, which scared him. "Oh, my God!" he exclaimed, "I just looked out the window and the LM wasn't there." Scott laughed and said it would be "pretty hard [not to] have a LM out there . . . with Jim in the tunnel." McDivitt put the hatch back in place until time to transfer into the lander. About an hour later, an ejection mechanism kicked the docked spacecraft away from the S-IVB. *Apollo 9* backed away, and the Saturn third stage, after firing twice, headed for solar orbit.²²

CHARIOTS FOR APOLLO

McDivitt's crew then turned to another trailblazing task—firing the service module propulsion system. Astronauts had in the past used one vehicle to push another into higher orbit,* but never a craft as big as the lander. Some six hours into the mission, they made the first test burn, which lasted five seconds. Flight controllers in Houston considered this the most critical of the docked service module engine firings. Scott must have agreed with them, because he exclaimed, "The LM is still there, by God!" The engine had come on abruptly, McDivitt later said; with the tremendous mass, however, acceleration was very slow—it took the whole 5 seconds to add 11 meters per second to the speed. Sixteen hours after this short burst, a second propulsion system ignition, lasting 110 seconds, included gimbal-ing (or swiveling) the engine to find out whether the guidance and navigation system's autopilot could steady the spacecraft. The autopilot stilled the motions within 5 seconds.²³

The crewmen grew more and more confident that they could handle their machines. And that was a good thing, since they next had to make a 280-second burn, to produce an added velocity of 783 meters per second. This lightened the service module's fuel load by 8462 kilograms and made it easier to turn the vehicles with the reaction control jets. The firing also altered the flight path and raised the apogee of the orbit from 357 to 509 kilometers, to provide better ground tracking and lighting conditions during the rendezvous. Scott later reported that they had the sensation that the docked vehicles were bending slightly in the tunnel area, but the maneuver produced oscillations only one-third to one-half as large as they had expected from training. As the big engine fired, McDivitt commented, "SPS . . . is no sweat." The astronauts were growing so used to the propulsion system that they hardly mentioned its fourth burn. Perhaps they were thinking of their next trailblazing chore, when two of them would crawl into the lunar module and check out its systems.²⁴

After they woke in the morning† and ate breakfast, McDivitt and Schweickart put on their pressure suits. Schweickart suddenly vomited. Fortunately, he kept his mouth shut until he could reach a bag. Although he did not feel particularly nauseated, both he and McDivitt became slightly disoriented when getting into their suits. For a few seconds, they could not tell up from down, which gave them a queasy feeling. Scott, already dressed, removed the command module hatch, the probe, and the drogue from the tunnel so his colleagues could get into the lunar module. Schweickart slid easily through the 81-centimeter tunnel, opened the lunar module hatch, and went next door in the first intervehicular transfer in

* John Young and Michael Collins aboard *Gemini X* and Conrad and Richard Gordon in *Gemini XI* had boosted their spacecraft to higher altitudes with the help of the Agena.

† For the first time in an Apollo mission, all three crewmen slept at the same time.

space. After he had flipped all the necessary switches, Schweickart reported that the lander was certainly noisy, especially its environmental control system.

McDivitt followed Schweickart into the lunar module an hour later. Within a brief time, a television camera had been unstowed and their activities were being beamed to the earth. Then they shut themselves off from Scott by closing their hatch while he was sealing himself off from *Spider*. A key event in lunar missions would be the deployment of the landing gear. A second or two after Schweickart pushed the button, the lunar module's legs sprang smartly into place. After the vehicles separated, the lunar module would flip over so the command module pilot could make sure all four legs were in the proper position.

Then Schweickart was sick again, and McDivitt asked for a private talk with the medical people. Although the news media were quickly informed of Schweickart's problem, this request for a "private" discussion was like waving a red flag, causing repercussions and a spate of unfriendly stories.* On this second occasion, the impulse to vomit came on just as suddenly as it had earlier, while Schweickart was busy flipping switches. Afterward, he felt much better and moved around the cabin normally, but he had lost his appetite for anything except liquids and fruits for the remainder of the voyage.²⁵

As soon as he was sure the systems were operating properly, McDivitt asked Scott to put the command module into neutral control, so he could check out the lunar module's steering system. McDivitt then operated the small thrusters to get the docked vehicles into the correct position for firing the lunar module's throttleable descent propulsion system. Seconds after starting the large descent engine, McDivitt shouted, "Look at that [attitude] ball; my God, we hardly have any errors." Twenty-six seconds later, at full thrust, he reported that errors were still practically nonexistent. In fact, things were going so smoothly that halfway through the 371.5-second exercise, the commander felt hungry—not an uncommon sensation with him. So he ate before crawling back into the command module. Schweickart stayed behind to shut everything down and straighten up the cabin before joining the others in *Gumdrop*. The lander appeared to be a dependable machine.²⁶

After Schweickart had vomited on two occasions, McDivitt was doubtful that the lunar module pilot would be able to handle his chores outside the spacecraft. The commander recommended to flight control that this exercise be limited to cabin depressurization. Flight control agreed that the

* Since it had been over so quickly, leaving no aftereffects, Schweickart's first sickness had not been reported to the ground. When it happened again, four hours later, McDivitt asked for medical advice, which started the controversy.



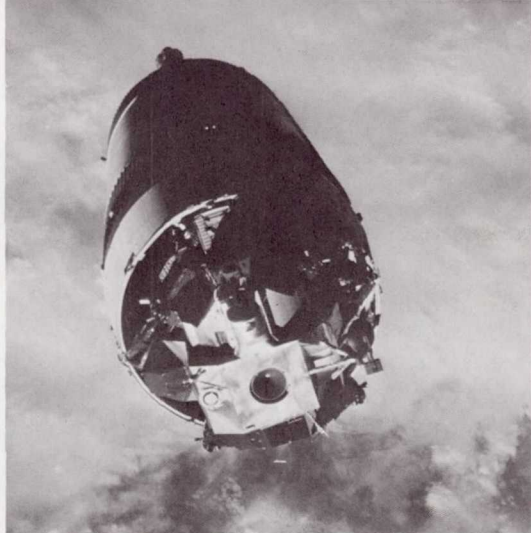
NASA officials Wernher von Braun (center) and George Mueller (with headphones) wait with Vice President Spiro Agnew in the launch control room at Kennedy Space Center for the Apollo 9 mission to lift off.

extravehicular activity would consist of one daylight period, with Schweickart wearing the portable life support system and the lunar module umbilical hoses,* and with both the lunar module and command module hatches open. On the fourth day of flight, working his way into the lander to get it ready, Schweickart felt livelier than he had expected. By the time he had put on the backpack, McDivitt was ready to let him do more—to stand on the porch at least. Flight control told the commander to use his own judgment. So McDivitt fastened Schweickart to the nylon-cord tether that would keep him from floating away from the spacecraft.²⁷

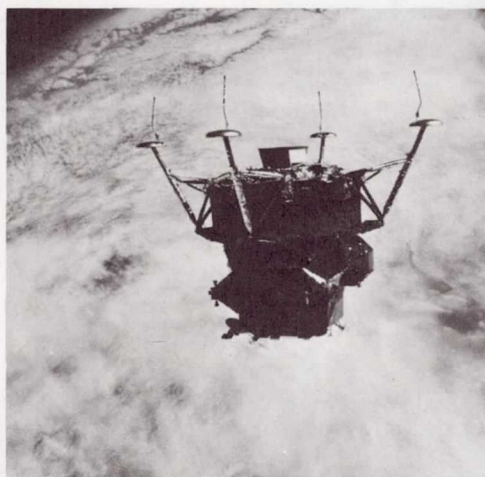
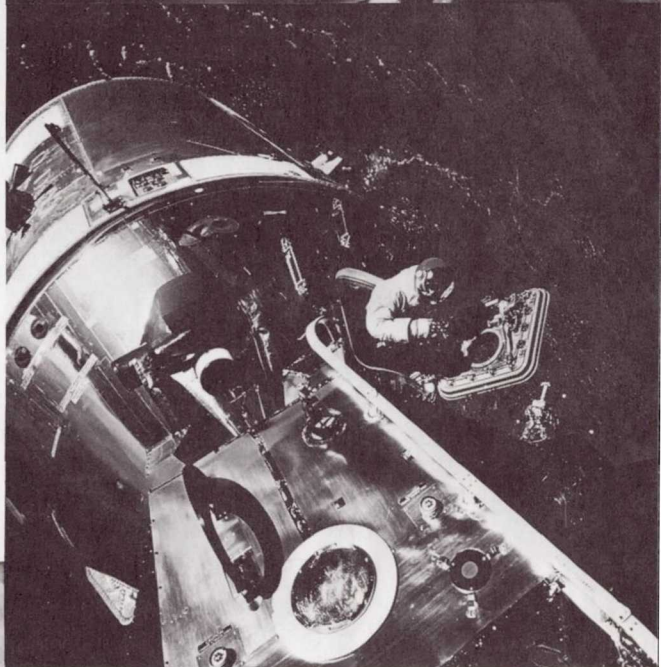
Once Schweickart had entered this “third spacecraft,” to become essentially a self-contained unit, flight control ran a communications check with *PLSS*, as they first called him. The four-way conversation—between *Spider*, *Gumdrop*, *PLSS*, and the Houston control center—was much clearer than they had expected. Lunar module depressurization also went smoothly. Schweickart could tell that his backpack was operating, since he could hear water gurgling while he watched his pressure indicator. He was quite comfortable. McDivitt had to use more force than he had anticipated to turn the hatch latch handle and more strength to swing the hatch inside. He was very careful to keep the door pushed back, fearing it might stick closed, leaving Schweickart outside.²⁸

Once the lunar module hatch was opened, Scott pushed the command module hatch outward. Schweickart, who now called himself *Red Rover* because of his rust-colored hair, enjoyed the view and did so well outside on the platform in the golden slippers that McDivitt decided to let him try out the handrails. Hanging on with one hand as he moved about, he took

* For operations outside the spacecraft, Apollo astronauts wore an extravehicular mobility unit (EMU), consisting of a pressure-garment assembly with helmet and integrated thermal garment; gloves; visor assembly; boots; liquid-cooled undergarment; portable life support system (PLSS, or backpack), with communicators and remote control unit; and oxygen purge system. Total cost of the EMU was \$400 000.



Apollo 9 flight, 3-13 March 1969. After reaching earth orbit, the crew separated from the Saturn V's S-IVB stage and turned the command module around to face the lunar module, still attached to the stage (above). Command module pilot Scott maneuvered the CM probe into the dish-shaped drogue on the LM and pulled out the lunar craft. At top right, Schweickart stands with camera in hand on LM Spider's porch to be photographed from the CM by Scott. At lower right, Scott, standing in the open hatch of CM Gumdrop, is photographed in turn by Schweickart. Below, McDivitt and Schweickart show Spider's landing gear to Scott before they pull away to evaluate lunar module operations. Spider is flying upside down to the earth far beneath.



CHARIOTS FOR APOLLO

photographs and found that the handholds made everything easier than it had been in simulation, even in underwater training. He did not go over and visit Scott in the command module, but both pilots retrieved experiment samples from the spacecraft hulls. Scott and Schweickart also took pictures of each other, like tourists in a strange country. Originally scheduled to last more than two hours, the extravehicular period ended in less than one, partly because they did not want to tire Schweickart after his illness and partly because they had plenty to do to get ready for the next day's pathfinding activity, the key event of the entire mission: the separation and rendezvous of the lunar module and the command module. With the door closed and their life-sustaining outside equipment off, McDivitt and Schweickart recharged the backpack, tidied up the cabin, and returned to the command module.²⁹

On both occasions when they had transferred to the lander, the pilots had been behind the schedule. On 7 March, they got up an hour earlier than usual. They also obtained permission from flight control to move into the lunar module without helmets and oxygen hoses, which made it easier to go through the checklist and to set up the module for the coming maneuvers. Soon both spacecraft were ready. When Scott tried to release the lunar module, however, it hung on the capture latches. He punched the button again and the lander dropped away. McDivitt watched the widening distance between the two craft. *Spider* then made a 90-degree pitch and a 360-degree yaw maneuver, so Scott could see its legs.³⁰

After drifting around within 4 kilometers of the command module for 45 minutes, McDivitt fired the lunar module's descent propulsion engine to increase the distance to nearly 23 kilometers. The motor was smooth until it achieved 10-percent thrust. When McDivitt advanced the throttle to 20 percent, the engine chugged noisily. McDivitt stopped throttling and waited. Within seconds, the chugging stopped. He accelerated to 40 percent before shutting down and had no more problems. McDivitt and Schweickart checked the systems and fired the descent engine again, to a 10-percent throttle setting; this time it ran evenly. As they moved off in a nearly circular orbit 23 kilometers above the command module, they had no trouble seeing *Gumdrop*, even after the distance stretched to 90 kilometers. From the command module, Scott could spot the lander as far away as 160 kilometers with the help of a sextant. Estimating distances was difficult, but the radar furnished accurate figures.

This new orbit, higher than that of the command ship, created the paradox associated with orbital mechanics of speeding up to go slow. Being higher above the earth (i.e., farther out from it) than the command module, the lander took longer to circle the globe. *Spider* gradually moved away, trailing 185 kilometers behind *Gumdrop*. To begin the rendezvous, McDivitt and Schweickart flipped their craft over and fired the thrusters against the flight path to slow their speed enough to drop below the com-

mand module's orbital path. Below and behind the command module, they would begin to catch up. They fired the pyrotechnics to dump the descent stage and leave it behind. The firing produced a cloud of debris and caused their blinking tracking light to fail. McDivitt commented that staging was "sort of a kick in the fanny . . . but it went all right."³¹ The distance between the lander and the command module soon shortened to 124 kilometers. McDivitt blipped the ascent engine for three seconds to circularize their orbit and begin a chase that would last for more than two hours. As the gap between the two craft narrowed, McDivitt spotted a very small *Gumdrop* at 75 kilometers.

About an hour after the ascent engine firing, McDivitt and Schweickart lit off their spacecraft's thrusters. "It looks like the Fourth of July," McDivitt commented, and Scott responded that he could see them very clearly. When the thrusters stopped, however, *Spider*, without its tracking light, was hard for Scott to spot. At that point, remembering the problem they had breaking away, McDivitt told Scott to make sure the command module was ready for docking. As he approached the other craft, the commander turned his machine in all directions so Scott could inspect its exterior. More than six hours after leaving the command module, McDivitt settled the lander firmly back into place and then reported, "I have capture." The 12 latches on the docking ring caught the lunar module and held it fast. Another stretch of the trail to the moon had been blazed. The lunar module could leave the command module, find its way back to it, and dock safely.³²

Even before crawling back into the command module, McDivitt said he was tired and ready for a three-day holiday. Another 140 hours would pass before touchdown in the Atlantic, but the crew had achieved more than 90 percent of the mission objectives. There were still things to do, such as making more service module engine burns (a total of eight throughout the flight) and jettisoning the ascent stage. Ground control radioed a firing signal to park the lunar module in a 6965- by 235-kilometer orbit. The crew watched the departing craft a while and then settled down to the more mundane tasks of checking systems, conducting navigation sightings, and taking pictures.³³

After 151 revolutions in 10 days, 1 hour, and 1 minute, *Apollo 9* splashed safely down in the Atlantic, northeast of Puerto Rico, on 13 March 1969, completing a 6-million-kilometer flight that had cost an estimated \$340 million. Less than an hour later, the crew was deposited, by helicopter, aboard the carrier U.S.S. *Guadalcanal*. Then the debriefings and celebrations began. At a ceremony in Washington, with an address by Vice President Agnew, lunar module development leaders Carroll Bolender of the Manned Spacecraft Center and Llewellyn Evans of Grumman were given the NASA Exceptional Service Medal and NASA Public Service Award, respectively. NASA officials were stimulated by the path-breaking

CHARIOTS FOR APOLLO

voyage of *Apollo 9*. They were now ready for the final rehearsal, a mission that would take Apollo back to the vicinity of the moon.³⁴

SETTING THE STAGE

From a technical standpoint, Apollo 10 could have landed on the moon. It probably would have—with some offloading of fuel to shed a little weight—had the flight been scheduled for the last few weeks of the decade. There were, however, good reasons for waiting until the next mission for a landing. Only two lunar modules had flown, and both those flights had been in earth orbit. NASA managers wanted to see how the lander's guidance and navigation system would behave in the moon's uneven gravity fields while the craft was within rescue range of the command module. Further, helium ingestion, which had caused *Spider's* descent engines to chug, would have to be investigated before a lunar module landed on the moon. Flight control also wanted a chance to review operation, tracking, and communications procedures of both vehicles while they were actually in the vicinity of the moon. The crews and controllers had been through many simulations, but it would take a real mission to give them the confidence they needed. Apollo 10 was to be a dress rehearsal, complete with a cast that included a lunar module capable of a lunar landing.³⁵

The basics of the mission plan had been conceived in the spring of 1967. When, the next autumn, Low and his men outlined the alphabetical sequence of the route to the moon, Apollo 10 was assigned the "F" role, a lunar-orbit flight with all components. Toward the end of 1968, the mission planning and trajectory analysis people in Houston, led by John Mayer, Tindall, and Carl Huss (all veterans dating back to Mercury), buckled down to work out the refinements.

One feature was a two-phase lunar-orbit insertion maneuver introduced on *Apollo 8*. The vehicle would begin the first revolution of the moon in an egg-shaped orbit, to avoid an unsafe pericyynthion (known in earth orbit as a perigee—that is, the lowest point). If the service module engine fired too long and slowed the speed too much on the first burn, that part of the circuit must not be so low that the spacecraft would crash into the lunar surface. On Borman's mission the engine had fired for an excess of almost five seconds. On the next burn, to circularize the orbit, the duration of the firing was adjusted to keep the craft a safe distance above the moon. "Weren't we smart?" Tindall asked his colleagues, when this became a standing procedure for Apollo 10 and the lunar landing missions that followed.

As first planned, the lunar module on Apollo 10 would simply pull away from the command module and return for rendezvous and docking; but in December 1968 Tindall and the mission planners began campaigning to put the descent propulsion system through a real test down near the

surface, where the landing radar could be fully checked. Moreover, they plotted the path so the lunar module crew could fly close enough to look for landmarks and take pictures of the site selected for the first landing. Tindall wanted them to go even farther—almost to touchdown—and then to fire the ascent engine to get back to the command module in a hurry, as though there had been an emergency. He had a fair hearing, he later said, but the mission planners did not think they had enough experience in the lunar environment to attempt this maneuver on the lander's first moon flight. Tindall reluctantly agreed. And there were many more procedures to be decided on and worked out before the flight plan became "final" in April 1969.³⁶

When LM-4 arrived in Florida during October 1968 (the descent stage on the 11th and the ascent stage on the 15th), the Kennedy Space Center inspection team led by Joseph M. Bobik found it was a much better machine than LM-3; they had very little to grumble about. NASA was also quite satisfied with CSM-106* and with North American's performance in its checkout and delivery to the Cape on 25 November 1968.³⁷

Although the contractors had shipped excellent spacecraft, preparations at Kennedy did not go lickety-split from the assembly building to the launch pad. Staying out of the way of *Apollo 9* preflight activities delayed testing several days. And during maintenance to the Launch Control Center, the electrical power was cut off to replace a valve. The Apollo 10 launch vehicle's pneumatic controls sensed the power cutoff, opened some valves (the normal failure mode for these components), and dumped 20 000 liters of fuel (RP-1—similar to kerosene) on the pad. Besides losing the propellant, the fuel tank bulkhead buckled. Technicians applied extra pressure to the tank, which removed all but a few wrinkles. Later the vehicle preparation team lowered a man inside to inspect the tank; he could find no further damage. Tests of the stage through the first week in May 1969 revealed no loss of structural integrity.³⁸

Actually, neither spacecraft nor booster preparations held up the launch a single day, although adjustments in the launch date for other reasons probably helped the hardware teams to maintain schedules. On 10 January, NASA changed the anticipated sendoff from 1 to 17 May to fit the lunar launch window (optimum position of the moon in relation to earth for this mission) and to provide more time for crew training. Then on 17 March Phillips postponed the liftoff till the second day of the launch window (to 18 May), so the crew could get a better look at candidate landing sites.³⁹

LM-4 and CSM-106 went through their flight readiness reviews on the same day, 11 April, with very nearly the same men passing on the lunar

* CSM-105 had been assigned as a ground test spacecraft in May 1968.

CHARIOTS FOR APOLLO

module in the morning and the command and service modules in the afternoon. During the lander review, a suggestion was made that the descent engine's chugging during McDivitt's flight might have been a form of pogo, but Low told Phillips that Faget's engineers had found no such indication. On 16 May, Phillips assured Mueller that all hardware would be ready for the mission two days later.⁴⁰

On 13 November 1968, NASA had announced that the prime crew for Apollo 10 would be Thomas Stafford, John Young, and Eugene Cernan, with Gordon Cooper, Donn Eisele, and Edgar Mitchell as backups, and Joseph Engle, James Irwin, and Charles Duke as the support team. Coming from understudy roles on *Apollo 7* in the leap-frogging crew selection methods that had evolved during Gemini, the Stafford group was the first all-veteran crew sent into space by the Americans.* Stafford had flown two missions (*Gemini VI* and *IX*), Young two (*Gemini III* and *X*), and Cernan one (*Gemini IX*).

The Apollo 10 crew had about 5 hours of formal training for each of the 192 hours it would spend on the lunar-orbital trip. Completely satisfied with the training program ("down to the nth degree," as Stafford later said), the crew was especially pleased with the time spent in the simulators. Putting Stafford and Cernan in the lunar module simulator and Young in the command module trainer and then linking them with mission control provided situations remarkably like those faced during actual missions. They had four or five such sessions in the Houston simulators. When they arrived at the Cape, they would practice rendezvous maneuvers in no other way. During the more than 300 hours each man spent in the simulators, other tasks—such as reentry, launch abort, transearth injection, and translunar injection—were also studied. That this was a veteran crew was readily apparent in later remarks about such training aids as planetariums (Cernan said they had been looking at the stars for five years) and the centrifuge (Stafford said he had not been in one since *Gemini III*).⁴¹

Stafford's crew picked its flight patch in March. The patch displayed two craft flying above the lunar surface, with a Roman numeral X and the earth in the background. The astronauts also selected their call-signs, "Charlie Brown" for the command module and "Snoopy"† for the lander. Julian Scheer, NASA's public affairs administrator, greeted these nicknames, as well as those of *Spider* and *Gumdrop* for *Apollo 9*, with raised

* During all phases of Apollo—seven more lunar flights, three Skylab missions, and one Apollo-Soyuz Test Project flight—there was only one other all-veteran crew: Neil Armstrong, Edwin Aldrin, and Michael Collins on *Apollo 11*.

† These names—of a small boy and a beagle—were borrowed from the popular comic strip "Peanuts," created by Charles L. Schultz. Schultz' drawings were also used by NASA to promote manned space flight safety awareness. Persons making notable contributions in this field were given "Silver Snoopy Award" pins by the astronauts.

eyebrows. He wrote Low that something a little more dignified should be picked for Apollo 11, the mission scheduled for the first lunar landing.⁴²

Apollo 10: THE DRESS REHEARSAL

On 18 May 1969, a king,* some congressmen, other distinguished guests, and a hundred thousand other watchers waited at scattered vantage points around the Cape area. At 49 minutes past noon, Rocco Petrone's launch team sent *Apollo 10* on its way to America's second manned rendezvous with the moon. Humming along at first like a Titan II, or so its Gemini-experienced crewmen felt, the gigantic Saturn V first stage suddenly slammed Stafford, Cernan, and Young forward and backward, until the cabin dials blurred before their eyes. Stafford tried to tell chief Flight Director Glynn Lunney's mission control team when the first stage of the vehicle dropped off but he could not squeeze the words out. When the remainder of the stack steadied, the S-II second stage (already firing) had the same pogo tendencies. The three astronauts had begun to wonder if the vehicles would hold together, especially the lunar module below them, when the S-IVB third stage fired, growling, rumbling, and vibrating as it shot into earth orbit.⁴³

During the systems review period, the ride smoothed. Lunney checked the men at the monitors in the control room and they all voted to fire for translunar injection. Stafford's crewmen considered not wearing their helmets and gloves but "chickened out," as Young phrased it, and put them on. They probably found the extra garb comforting when the S-IVB fired, because the third stage again groaned and shook. None of the three were confident of being able to continue the trip much longer, and Cernan wondered how the mission could be safely aborted at this point in space. The guidance system kept *Apollo 10* on a steady course, however, and they were on their way.⁴⁴

When Young pulled the command module away from the S-IVB, the crew saw the panels that had housed the lunar module drift away. After the command module was flipped around, it was 45 meters away from the third stage, about three times farther than intended, but it would take only a little extra gas to get back for docking. As the CM moved around, the mission controllers on the ground watched the maneuvers, in "living color."

Television had worked so well on other Apollo flights that NASA had decided to put a color system on Stafford's command module. Weighing only 5.5 kilograms, the Westinghouse camera included a 7.5-centimeter monitor to show the astronauts what they were transmitting. Now flight con-

* King Baudoin and Queen Fabiola of the Belgians flew to KSC on *Air Force One* two hours before liftoff.

CHARIOTS FOR APOLLO

trollers watched along with the crew as *Charlie Brown*, perfectly aligned with his target, pulled up to *Snoopy*, latched onto him, and drew him out of his doghouse. Shortly thereafter, with signals to Houston through the big antenna dish at Goldstone, California, a vast populace saw a color view of a large portion of their western hemisphere from thousands of kilometers in space.⁴⁵

After checking tunnel, latches, and docking probe, the crewmen had a light workload as they coasted toward the moon. They were grateful for even such small jobs as firing the thrusters to make slight corrections in spacecraft attitude, but this was so seldom necessary they began to wonder if the jets were working. On occasion, however, when nothing was firing, the whole stack shimmied. They later speculated that this may have been caused by fuel sloshing. When making optical navigational sightings, the crew had trouble acquiring enough stars for an accurate reading. Without the optics, the men could see no stars at all for a long time. Finally, Stafford spotted a few dim orbs after he had traveled 190 000 kilometers into space. But not much navigating was needed; the course was so true that the service module propulsion system was used only once, to add 15 meters per second to their speed, at 26 hours into the voyage. This firing put the spacecraft on a lunar path that would lead the crew over the exact spot where the first landing might be made. The rest of the time the astronauts studied the flight plan, slept, ate, and beamed five excellent television transmissions back to the earth.⁴⁶

Stafford, Cernan, and Young were the first Apollo pilots to be free from illness during the mission, although Cernan experienced a slight vestibular disturbance. Like all their colleagues who had flown before, once they unbuckled from the couches they had a stuffy feeling in their heads. This lasted for 8 to 10 hours for Stafford and Young; Cernan gradually lost the sensation over the next two days. He practiced "cardinal head movements" that the medics thought might help overcome his slight feeling of nausea. Although he was able to do the exercise for more than four minutes at a session by the seventh day of flight, when he returned to earth he lambasted the procedure, saying it must have been designed to bring on illness rather than to alleviate it.⁴⁷

The crew slept well, although thruster firing bothered Cernan the first night. Later, when they were circling the moon, the men were glad that McDivitt's crew had suggested they carry a sleeping bag apiece. The spacecraft grew cold once the windows had been covered to darken the cabin for sleeping.

One major complaint the astronauts registered was about their water supply. They were supposed to chlorinate it at night; because of an error in procedures passed to them by flight control, Stafford had a double dose of chlorine when he took a drink during the first breakfast of the trip. This was unpleasant, but it posed no major problem. Something else in the water

supply did. When earlier crews had complained about gas in the water system, a new water bag was designed, with a handle the crew could use to whirl the bag around to separate the gas from the water. It did not work. The gas settled to the bottom of the bag and then remixed with the water when the crew members tried to drink. The gas worried them; they could envision getting diarrhea, which would have been difficult to cope with during flight. They did have gas pains and cramps but, fortunately, nothing more.⁴⁸

Poor water quality may have affected their appetites, for the astronauts on this flight were not big eaters. On occasion, they skipped meals. Stafford estimated they had enough food to last for 30 days. Not all the blame could be laid on the water, however; the food was still no epicurean delight. Back on earth in early May, Donald D. Arabian, chief of the Apollo Test Division, had tried a four-day supply of their rations. Arabian claimed to be "somewhat of a human garbage can," but even he lost his desire for food on this diet. The sausage patties, for example, tasted like granulated rubber and left an unpleasant taste. With all the difficulties of preparation, Arabian added, by the third day continuing the test was a chore. He did like the items that were closest to normal table foods. Stafford's crew also found some of the newer dishes that could be eaten with a spoon quite palatable. But the men dreaded reconstituting the dehydrated meals, knowing that the water contained so much gas.⁴⁹

Unlike Borman's crew, which could not see the moon with the unaided eye until the spacecraft was almost upon it, Stafford's group spotted it on the second day of flight. On the earth, it looked like a waxing crescent, but Stafford and Young, with the help of earthshine, could see almost a full moon. Although the moon was much bigger at 200 000 kilometers above the earth, landmarks on the lunar surface still could not be picked out. Cernan also asked flight controllers if they thought he could really recognize the S-IVB stage 5600 kilometers away, because that was what he thought he was seeing. The CapCom told him that the men in the control room were nodding their heads yes and that the distance between the two vehicles actually measured 7400 kilometers.⁵⁰

When *Apollo 10* reached the lunar vicinity on 21 May, the controllers informed the crewmen that at one time or another more than a billion persons had watched their televised activities. But interest now focused on the exact moment when their craft would shoot around the moon and lose communications with the earth. At 74 hours 45 minutes into the mission, flight control predicted that loss of signal would come at 75 hours, 48 minutes, 24 seconds. The controllers had already determined that the ship would reach the moon 11 minutes later than scheduled, since there had been only one midcourse correction, rather than two. Its trajectory would be 110 kilometers above the lunar surface.⁵¹

The crew was impressed by the lunar landscape, although Stafford

CHARIOTS FOR APOLLO

insisted it looked like a big plaster of Paris cast. The three found it almost incredible that someone back on earth had been smart enough to place them within 110 kilometers of the moon—but there they were. They caught just a glimpse of the surface a minute before they fired the service module engine to go into lunar orbit, an activity that required all their attention. The six-minute retrograde maneuver seemed interminable, just as it had to Borman's group, but the engine kept firing and their confidence in it kept growing. When the engine finally shut down and they were sure that it had done its job, Stafford and Cernan had time to look at the lunar surface. They likened one area to a volcanic site in Arizona. Finally Stafford forced his attention back inside the cabin and told his crewmates that he thought the best thing to say when they got back in radio contact was, "Houston, tell the earth we have arrived."⁵²

Stafford, Young, and Cernan were fascinated by how much more slowly they seemed to travel around the moon than they had around the earth. They liked the slower pace, because on the first circuit they would pass directly over the area where Apollo 11 was due to land two months later. They had barely rounded the corner before Stafford and Cernan began describing the physical features down the highway they called "U.S. 1," leading to the landing site. By the third circuit, the world was sharing the view on color television. Watchers could see the gray, white, black, and brownish tints of the landing site, which seemed to be free from boulders, providing a smooth landing field.⁵³

Six hours after reaching the moon, Cernan and Stafford began getting the lander ready. The hatches, probe, and drogue were easily removed. As he entered the lunar module, Cernan was greeted by a snowstorm of mylar insulation, apparently sucked into the vehicle through a vent from the tunnel. The insulating material had come loose in the tunnel, and the crewmen had spent some time capturing and cleaning it up in the command module. Now they had the same job to do in the lunar module.

Cernan had floated head down through the tunnel into the lunar module. Because the two spacecraft were locked together from top to top, his own private world had a new orientation. He later commented that the best way to handle this psychologically was to slide through the hatch, look around, and then mentally assign an arbitrary up and down. Once he had accepted the new environment, he had no problems in checking, hauling in equipment, and getting things in order. The crew had intended to leave the passageway to the lander open after returning to the command ship, but the hardware was too bulky. It was simpler, and quite easy, to put the probe and drogue back into place.⁵⁴

Flight control had planned to let the crew sleep until the last moment on 22 May, when Stafford and Cernan would leave Young and fly the lander down near the lunar surface. But, after playing "The Best Is Yet to Come" and sounding reveille, ground control found that the astronauts had

stealthily risen, eaten breakfast, and quietly begun work on the flight plan checklist. Cernan removed the encumbrances from the tunnel and zipped over into the lunar module to get everything ready, while Young helped Stafford with his suit (a five-minute job even with assistance).^{*} Cernan then came floating back into the command module and jumped into his suit. When flight control heard from them at the start of the tenth circuit, the two pilots were in the lander and closing off the tunnel.⁵⁵

When Stafford and Cernan were ready for undocking, however, they found that the lunar module had slipped three and a half degrees out of line with the command module at the latching point, possibly because of loose mylar collecting on the docking ring. It might also have happened when Young, during docking, had forgotten to turn off the service module roll thrusters and flight control had been tardy in reminding him of the task. Whatever caused the problem, the crew feared separating the two craft might shear off some of the latching pins, possibly preventing re-docking. Stafford and Cernan would be stranded in lunar orbit with no way back except by going out the lander hatch and making their way to the command module hatch—a dangerous undertaking. But Low, who was in the control room at the time, told Flight Director Lunney that as long as the misalignment was less than six degrees they could go ahead and undock.⁵⁶

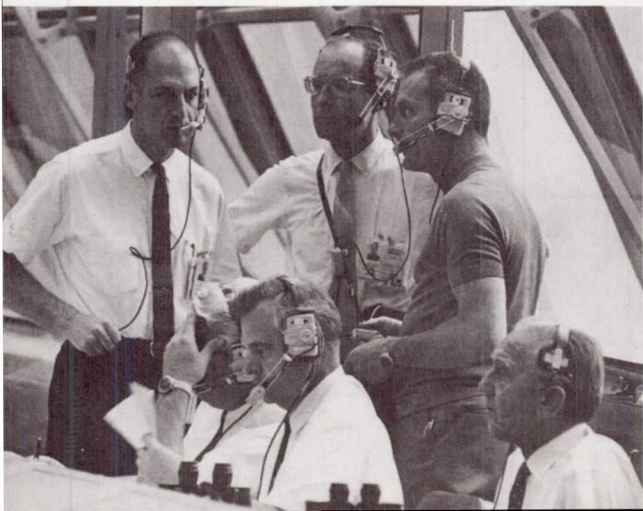
Just before *Apollo 10* rounded the corner to the back of the moon, flight control passed the good news to Stafford. The two crewmen in LM *Snoopy* heard a “pow” as they broke free. Young, all alone in what now seemed to be an unusually large command module, turned on the television camera so the flight controllers back on the earth could help him inspect the lander. Meanwhile the lunar module landing gear had deployed and was in place. The lander’s systems checked out well, especially the radar, the abort guidance system, the antennas, and the pressurization of the descent propulsion system. Everything looked good, and everybody was ready to go. Telling Young not to get too lonesome and not to go off and leave them, Stafford and Cernan announced that they were ready to go down and snoop around the moon.⁵⁷

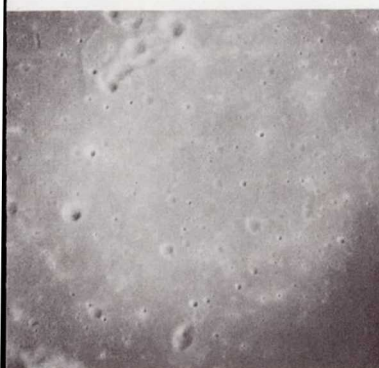
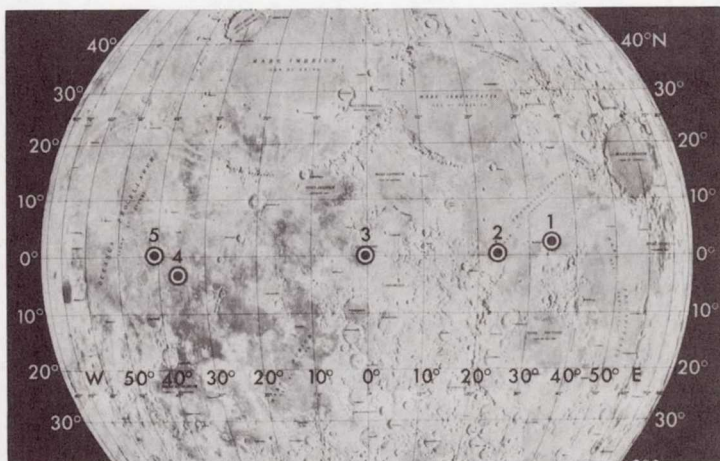
Young had used his service module thrusters to pull *Charlie Brown* nine meters away from the lunar module for the inspection. He then gave the same jets a spurt to thrust downward toward the moon until the two vehicles were three and a half kilometers apart. Stafford and Cernan were ready to try, for the first time, another of the operations with a significant

^{*} Getting into and out of the suits in the small lunar module would be difficult, the crewmen realized, although they found that putting them on was not too great a chore. Simpler procedures would have to be worked out for crews that would remain in the lander for longer periods.



Apollo 10: dress rehearsal for the lunar landing. In the launch control room 18 May 1969, Apollo officials (below, standing left to right) George Low, Samuel Phillips, Donald Slayton, and (seated left to right) John Williams, Walter Kapryan, and Kurt Debus listen to the countdown for the launch that would send three astronauts toward the moon. At 66 600 kilometers outward bound, the crew televised a near-circular view of the earth (right) to Mission Control and the public. They also photographed the view (above), showing much of the North American continent.





Selected Apollo lunar landing sites (above). The Apollo 10 crew photographed Sites 1, 2, and 3. Site 1 area (left) was on the eastern side of the Sea of Tranquility. Site 2 (center) was on the southwestern part of the sea. And Site 3 (right) was on the lunar equator, in Central Bay; topographic features are accentuated by the low-sun angle.

Young, by himself in CM Charlie Brown, said that LM Snoopy carrying Stafford and Cernan close to the moon below looked like a spider crawling on the lunar surface. Young photographed the returning lunar module, which successfully demonstrated the lunar-orbit rendezvous operations.



CHARIOTS FOR APOLLO

Apollo abbreviation so cherished by the engineers—descent orbit insertion, or DOI. At nearly 100 hours into the mission, Stafford started the descent engine at minimum thrust—which slowly built up past 10 percent—and then 15 seconds later he increased it to 40 percent for 12 more seconds. The engine ran smoothly, with none of the chugging experienced on McDivitt's ride. Young tracked the burn optically and told the lunar module crewmen that they were moving away from him at more than 20 meters a second. Cernan did not think they were going that fast. "It's a very nice pleasant pace," he said. Now they could get a close look at a proposed landing site in the Sea of Tranquility, where Apollo 11 might set down in July.⁵⁸

Stafford and Cernan had studied hard for what they were going to do. In a T-38 aircraft, they had simulated this trajectory above the earth. They had pored over charts and maps of the site, and they had scrutinized the area during their hours in lunar orbit. So the astronauts traveled easily down the approach path, calling out the names of craters, rilles, and ridges as they went along. They appeared to be traveling exactly over the track they wanted, reaching a low point of 14 447 meters above the surface. They took many pictures; then Stafford's camera failed as the film started to bind. He described the landing site as much like "the desert in California around Blythe." If a lander touched down on the near end, it would have a smooth landing, he said; but, if it wound up at the far end of the zone, extra fuel would be needed for maneuvering to a clear spot. Their landing radar worked perfectly when they tested it, and the pilots remarked that they had no visibility problems with lighting and sun angles.⁵⁹

Young caught sight of the lunar module at a distance of 120 kilometers; *Snoopy* appeared to be running across the lunar surface like a spider. At other times, using a sextant, he spotted the craft as far away as 550 kilometers. An hour after the first descent burn, Stafford and Cernan fired the engine again, to shape the trajectory for their return to the command module. Shoving the throttle forward for 40 seconds and 100 percent thrust, Stafford was happy to note that there was still no chugging. Young tried to see the flames from the engine but could not. Although the lander's speed had increased by 54 meters per second, the crew again had the impression that acceleration was slow. During these activities, the lunar module had a "hot [open] mike," which was fine with Young, since it kept him informed of what was happening in the lander. But whenever he talked, he had a feedback of his own voice. Somebody would have to fix that before the next mission, he said.⁶⁰

After Stafford's camera failed, he and Cernan had little to do except look at the scenery until time to dump the descent stage. Stafford had the vehicle in the right attitude 10 minutes early. Cernan asked, "You ready?" Then he suddenly exclaimed, "Son of a bitch!" *Snoopy* seemed to be throwing a fit, lurching wildly about. He later said it was like flying an Immel-

mann turn in an aircraft, a combination of pitch and yaw. Stafford yelled that they were in gimbal lock—that the engine had swiveled over to a stop and stuck—and they almost were. He called out for Cernan to thrust forward. Stafford then hit the switch to get rid of the descent stage and realized they were 30 degrees off from their previous attitude. The lunar module continued its crazy gyrations across the lunar sky, and a warning light indicated that the inertial measuring unit really was about to reach its limits and go into gimbal lock. Stafford then took over in manual control, made a big pitch maneuver, and started working the attitude control switches. *Snoopy* finally calmed down.⁶¹

For this first lunar module flight to the vicinity of the moon, the pilots were supposed to use the abort guidance system instead of the primary guidance system, to test performance in the lunar environment. The abort system had two basic control modes, "attitude hold" and "automatic." In automatic, the computer would take over the guidance and start looking for the command module, which was certainly not what the crew wanted to do just then. In correcting for a minor yaw-rate-gyro disturbance, the pilots had accidentally switched the spacecraft to the automatic mode, and the frantic gyrations resulted. From Cernan's startled ejaculation to Stafford's report that everything was under control took only three minutes. Flight control told the crewmen they had made an error in switching, but the system was fine. They could fire the ascent engine. After the firing, the lander flew what Stafford called a "Dutch roll," yawing and pitching and snaking along. When the engine shut down, however, to the crew's surprise the attitude and flight path to the command module were correct. From a maximum distance of 630 kilometers, the thrust from the ascent engine moved the lunar module to within 78 kilometers of the mother ship.⁶²

As the lunar module approached, Young saw it through his sextant at a distance of 259 kilometers. Stafford and Cernan got a radar lock on the command module shortly after the insertion burn and watched with interest as the instrument measured the dwindling gap between the vehicles and demonstrated the theories of orbital mechanics in actual practice. Cernan especially liked the steady communications that kept both crews aware of what was happening. After watching the command module from as far away as 167 kilometers and then losing sight of it at sunset, the lunar module pilots saw *Charlie Brown's* flashing light with their unaided eyes at 78 kilometers. At last, the two craft were only eight meters apart, and the relative speed between them was zero. Stafford did find the ascent stage a little difficult to hold steady, just as Conrad had suspected, but Young slid the probe smoothly into the dead center of the drogue. Stafford rammed the lunar module forward, and the capture latches closed with a loud bang.⁶³

Stafford and Cernan had been gone for more than eight hours, and they were ready to get back into the command module and rest. Transfer-



Apollo 10 crewmen Stafford, Young, and Cernan (left to right) meet the press at Manned Spacecraft Center on 7 June 1969 after return from their lunar-orbit mission.

ring equipment and closing the tunnel were easy. When all three were settled in, they cut the lander loose. Flight control then fired the ascent engine to fuel depletion (249 seconds) and sent the lunar module into solar orbit. The crew watched it move away; *Snoopy* was soon out of sight. Stafford and his crew went back to tracking landmarks on the surface below for the upcoming lunar landing mission.⁶⁴

After 31 circuits, the crew fired the service module engine to begin the return to the earth. On 26 May 1969, *Apollo 10* streaked through the early morning darkness like a shooting star, to splash down in the Pacific 690 kilometers from Samoa and only 6 kilometers from the prime recovery ship. The journey had taken 192 hours, 3 minutes, 23 seconds. A helicopter picked the crew up and carried them to the U.S.S. *Princeton* within the hour. This fantastic voyage was over and had revealed absolutely no reason why Apollo 11 could not negotiate the final few kilometers to the lunar surface. The trail had been blazed.⁶⁵

13

To Land on the Moon

1960–July 1969

When Apollo 11 stood on its launch pad in July 1969, NASA and contractor engineers had done everything they could to make sure it was ready for a lunar landing. In the eight years since President Kennedy had issued his challenge, thousands of persons had designed, developed, and figured out how to use the millions of pieces that made up the launch vehicle and spacecraft.¹ Confidence in this hardware had come from several flights, one of them to within a few kilometers of the target. By and large, then, worries about the last stage of the journey should have been few. Such an expectation, however, did not prove true.

Many of the prelaunch activities were peculiar to the Apollo 11 mission. Landing on the moon, walking on its alien surface, and then leaving it (all new experiences) affected other areas. For example, the lack of knowledge about the problems a crewman might encounter as he moved about in low gravity in the “third spacecraft”—a bulky suit and backpack—raised numerous questions. What would he do? How long would he stay? How far would he explore? And what kind of experiments would he set up for scientific interests? Some scientists worried that the astronauts might bring back pathogens to contaminate the earth. So the Lunar Receiving Laboratory became a quarantine facility as well as a place in which to store and study lunar soil and rocks. A precise protocol was drafted to keep the astronauts isolated from other Earthlings and to move them and their cargo from a Pacific splashdown to a special building in Houston with dispatch.

Crew training, already complicated by the need to master the controls of two different and very complex spacecraft, took on new dimensions, prin-

CHARIOTS FOR APOLLO

cipally in learning how to set a 14.5-metric-ton lunar module safely down on the moon. The astronauts practiced this task on fixed-base lunar module simulators in Houston and at the Cape, on a swinging suspension device at the Langley Research Center, and on a free-flight apparatus called a lunar landing training vehicle—a set of rocket motors laced together and supported by an odd-looking arrangement of pipes—at Ellington Air Force Base, Texas.

Landing men on the moon raised national and international issues never before faced in space flight. In the past, an explorer had implanted his country's flag on new soil to symbolize a territorial claim. When an astronaut raised the banner of the United States over lunar ground, would he be claiming the moon for America? Other symbolic acts and articles also prompted questions about man's first visit to the earth's moon. What tokens should he take with him, what should he leave there and what should he bring back, what memorable words should he say, and what ceremonies should he enact? NASA public affairs officials, more accustomed to responding to queries than to using the high-pressure selling tactics of public relations promoters, realized that they would have to answer these new questions almost before they were asked. They also recognized that public interest in Apollo might wane after the first landing. Apollo 11 must, therefore, tell NASA's story aggressively while a worldwide audience watched and listened.

From almost any vantage point, Apollo 11 was unique—a totally different venture from any the earth's people had ever embarked upon. But the men and women most directly responsible for this flight focused on mission techniques, crew training, space vehicles, and qualification of an extravehicular mobility unit, with only fleeting thoughts for what this mission might mean to the world.

SOME SPECIAL CONSIDERATIONS

NASA officials used only a dozen words to list the primary objectives of Apollo 11: "1. Perform a manned lunar landing and return. 2. Perform selenological inspection and sampling."² They had worked many years to be able to write these objectives for a mission rather than a program. Ever since Apollo was named in 1960, groups scattered throughout the country had studied and planned the segments of that mission. Through 1965, this planning had helped design the hardware. After that, with the exception of rework caused by the fire in 1967, the mission planners had analyzed the spacecraft capabilities and used this information to draft the most minute details of the flight plan, which appeared in "final" form on 1 July 1969, to be followed by "revision A" seven days later.³

Chris Kraft's flight operations team in Houston designed and evaluated most of the mission techniques. When the lunar landing flight became the

letter "G" on the chart of the progressive steps to land the first men on the moon, Rodney G. Rose had already presided over 21 monthly meetings on how the crew would operate when it reached its goal. The Rose team held 20 more meetings before being satisfied that it had done all it could to smooth operations for what turned out to be Apollo 11. The 41st and final (summing-up) session was held in April 1969, after a flight operations plan had been issued to outline in detail the duties and actions to be performed at precise times.⁴

Rose's group served two specific purposes. First, its members were observers, acquiring and passing on information about the spacecraft, about flight crew operational procedures tried and either adopted or rejected, and about engineering and development progress in qualifying the suit and backpack for the lunar walk. The committee was, second, a forum before which the mission planning and analysis team could air computer-checked trajectories and techniques that affected the interactions of hardware, crew, and fuel. Mission planners relied not only on theoretical plans run through the computers, but also on actual experience. *Apollo 8*, for example, needed only 2 periods of onboard navigation during translunar and transearth coasting, rather than the 10 previously planned. But past experience was set aside in one case. As far back as Mercury, the crews had dumped any remaining fuel before landing, as a safety precaution. What should be done about the propellants in the lander's descent and ascent propulsion systems? Should one be burned to depletion before lunar touchdown and the other before redocking with the command module? The Apollo office objected to this. It would be safer for the lunar module pilots to land as soon as they reached the selected site than to cruise around burning up fuel, with the possibility that they might have to touch down in an undesirable site as a result. And it would be much better to go ahead and dock than to fly around until they were low on fuel and then find, if an emergency arose, that they had no way to return to the command module. Firing to depletion in either case would be a last-ditch action to ensure crew safety.⁵

Rose's team also helped Donald Slayton's support personnel decide how many lunar revolutions should be flown before undocking and descent, to make sure a well-rested crew would land on the moon with the sun angle at 6 to 20 degrees, for the best lighting. *Apollo 10* supplied the answer to this question. But the planners and trajectory plotters could not set a specific flight path in concrete. With the possibility that delays could cause them to miss a launch window (determined by the moon's position in relation to the earth), they had to plan for one mission in July, for another in August, and for a third in September.⁶

Closely allied with Rose's work were the activities of Bill Tindall. Long an associate of John Mayer in mission planning, Tindall had guided Gemini efforts while Mayer had concentrated on early phases of Apollo planning. When Gemini ended in 1966, Tindall had jumped in to help out on the

CHARIOTS FOR APOLLO

complex Apollo task, first as Mayer's deputy and then as data coordination chief in the Apollo office. After 16 January 1968, the day he assumed his new duties, his barrage of "Tindallgrams" continued to enliven interoffice mails. Although he was now the liaison between spacecraft and operations people, Tindall had been and still was a mover of information and an assigner of tasks to specialists, either to devise or to solve some mission technique. His memoranda, sometimes addressed to hundreds of persons, often contained admonitions to one, such as, "Bob Ernull please take note."⁷

Three areas of the mission demanded the toughest scouting by Tindall, Rose, and other mission planners: descent, surface operations, and ascent. Judged by the sheer weight of paperwork, descent seemed to be the engineers' chief worry. Yet nobody wanted to set mission rules so narrow that the crew could not land. Tindall and astronaut Harrison Schmitt even discussed whether it was absolutely necessary for the pilots to see exact landmarks. A touchdown outside the targeted area might be quite satisfactory. They decided to leave the pilots some options: "quit and come home, go another revolution and try again, or don't worry about it and press on with the landing."⁸

Much of the concern about hitting a precise spot stemmed from uncertainties about trajectory dispersions caused by the moon's strange gravity fields. As more information was gathered about the mass concentrations, called mascons, the Landing Analysis Branch fed the data into computers for run after run (205 on just one study), trying to evaluate fuel use and the probability of mission success based on varying degrees of mascon influence on the descent trajectory. Tindall's group also found guidance system faults that might result in unwanted excursions. Flight controllers would have to help the crew decide whether to go on or return to the command module. But returning to the mother ship would be tricky, Tindall said. Dispersions had to be severely contained to prevent the crew from flying a "dead man" curve—an aimless trip across the lunar sky far out of range of the command module's rescue capability.⁹

Constantly looking for clear explanations of how to guide a spacecraft safely down to the moon, Tindall pounced on a lucid description by George W. Cherry of the Massachusetts Institute of Technology and arranged to have it reproduced and distributed to flight controllers, managers, and astronauts. Cherry numbered each step of the descent phase and outlined the guidance in finite detail, including how the spacecraft should react and what the pilots should do. Cherry said that, during "program 63 (P63)" (braking), the crew should steer out any errors in attitude. During P64, as the lander tipped over to give the crew a first look at the landing site, the thrusters that turned and tilted the spacecraft should be carefully checked to make sure they were working properly for the landing. From there to touchdown—P65, 66, and 67—a maze of procedures would take the pilots through this most critical step in the mission.¹⁰

When the Sea of Tranquility appeared the possible target for Apollo 11, Tindall alerted planners to some unusual conditions in that location. Although the lunar module would begin its descent from an orbital station 18 300 meters above the mean surface of the moon, its altitude above the landing zone would be much less than that. Tranquility, he said, was 2700 meters above the mean average, and even more in its hilly area. So the landing approach would start low. Moreover, it would be uphill because there was a one percent upward grade in the direction of the flight path. These numbers, too, were fed into the computers to check the crew's responses as they flew the trajectories in the lunar module simulator. All through June and early July, memoranda and notes about descent—propellant margins, use of the guidance system, and even the views to be seen out the windows—continued to flow.¹¹

In March 1969, Tindall had reminded his colleagues that the "lunar surface stuff [was] still incomplete." Even the proper terminology had not been decided. For example, Tindall said, the past practice of continuing or aborting a mission by making a "go/no go" decision seemed inappropriate; once the lander had settled on the lunar surface, this might confuse the pilots. Tindall suggested something like "stay/no stay," and that phrase became standard.¹²

There were other lunar surface worries. Suppose the vehicle landed at an angle? That possibility did not worry the planners very much, because the LM was designed to take off with as much as a 30-degree list, but the guidance system did not know that. In flight, the attitude thrusters fired automatically to keep the lander on an even keel, and they would do the same thing on the ground. But nobody wanted these engines to fire while on the lunar surface. George Cherry had the answer. "Just joggling the hand-controller will not necessarily . . . stop the firing," he said; the crew would have to cycle the guidance switches to off and then to attitude hold to prevent the thrusters from doing their programmed job.

The two hours after landing were critical. The pilots—who would act as their own launch crew—had to go through a countdown after landing to be prepared to leave the moon in a hurry if anything went wrong. They would do the same thing the last two hours before their scheduled departure. One crucial task in both these exercises was aligning the guidance system's inertial platform. Most mission planners agreed that the moon's gravity could be used for this reading, but Tindall worried that the lander might be so near "one of those big damn lumps of gold" that the alignment might be wrong and the lander might take off on an incorrect course. Two days before launch, however, he reported that "the various far-flung experts predict that mascons should have no significant effect."¹³

Ascent from the moon also raised questions about trajectory dispersions. Fairly small deviations could cause the lunar module to crash back into the moon or miss the rendezvous with the command module. That was

CHARIOTS FOR APOLLO

not as big a worry, however, as the possibility of a failure in the guidance system. The chances of the crew's taking off in the lunar module and finding the command module would be extremely poor if all the guidance equipment failed.* Planners had been studying manual takeover and steering of the lander even before Grumman was selected to build the machine in 1962; in 1969 the computers were still grinding away, trying to find a satisfactory solution. The consensus appeared to be that controlling the lunar module manually was only slightly better than doing nothing.

And a launch from the moon had to be exactly on time. If the crew fell behind in the schedule, it would have to delay the launch until the command module circled the moon again. It was also important that the command module's path be precisely in line with the lunar module's ascent trajectory (that is, "in plane"). The command module pilot was responsible for tasks such as altering the command ship's flight path—not just watching from his window. He would participate actively by keeping a close eye on the lunar spacecraft while it was on the surface and by being ready to help deal with whatever contingencies the lander might encounter. To be prepared for any abort situation, the command module pilot had a "cookbook" of 18 different two-page checklists to cover all envisioned rescue operations.¹⁴

Landing, surface work, and ascent were going to be difficult, complex, and demanding tasks. George Mueller, the manned space flight chief in Washington, had therefore urged in mid-1968 that the first lunar landing crew be selected as soon as possible.¹⁵

TRAINING MANKIND'S REPRESENTATIVES

Chief Astronaut Donald Slayton established a leapfrog pattern of assigning a crew to back one mission, skip two, and then fly the next. When Neil Armstrong, with Fred Haise to pilot the lunar module and Edwin Aldrin the command module, was named to back up *Apollo 8*, it seemed likely that his team would make the first lunar landing, if the two intervening missions were successful. Then, in late 1968, after Michael Collins recovered from a bone spur operation, Slayton moved Haise to backup lunar module pilot, put Collins in as prime crew command module pilot, and shifted Aldrin to the lunar module pilot slot. Completing the backup teams were James Lovell (commander), William Anders (command module pilot), and a support team made up of John Swigert, Ronald Evans, William Pogue, and Thomas Mattingly (Slayton assigned Mattingly as a fourth support crewman after

* Mission planner Carl Huss had talked with the astronauts (especially Russell Schweickart) during the early days about manual control. At that time, however, his group thought the lander had enough redundancy and backup systems to do the job. As the landing flight drew near, astronaut interest in manual control naturally heightened.

President Nixon nominated Anders as Executive Secretary of the National Aeronautics and Space Council).¹⁶

One member of this lunar module crew would be the first man to walk on the moon—the first human being to step onto any celestial body besides the earth. The road leading to the determination of which pilot would have his name so registered in the annals of time was long, winding, and, in places, hard to follow.

In mid-1963, when the lunar module began to take on its final shape, NASA outlined the mission sequence to the news media in conservative tones. Emphasis was on the probability that one man would remain aboard to tend the lander's systems. There appeared to be no interest at the time in who would stay and who would get out. The following year, the agency identified the lunar module pilot to Congress and newsmen as the man who would take a two-hour hike on the surface, while the commander waited for his return. But the same year—1964—the Grumman-led Apollo Mission Planning Task Force study indicated that both men could safely leave the craft, one at a time, for up to three hours apiece. This group had no interest in which man went out first; it was merely looking at the mission sequence to ensure adequate hardware designs.¹⁷

During the succeeding years, Apollo officials Joseph Shea and George Mueller frequently spoke publicly on lunar surface operations. Shea said in July 1966 that the crewmen would take turns at the three-hour walks, perhaps going out as many as three times during an 18-hour stay. Mueller, speaking to an Australian audience two weeks before the fire in January 1967, made it sound rather as though both men would go out, arm in arm, when he remarked that “the two astronauts will disembark through the docking door and begin the manned exploration of the moon.”¹⁸ So far as is known, no one asked who would do these things—or how they would be done. With nearly 50 astronauts to choose from and with the names of most of them unfamiliar to the public, people found it difficult to conjecture about the identity of a moon-walking crew. In fact, after all the centuries of science fiction and all the years of Apollo's existence as a viable program, it was still hard to envision someone's actually landing on the moon.

By late summer of 1968, it was time to find out if the astronauts could unload and set up the experiments in the Apollo lunar surface experiments package (ALSEP), put together by The Bendix Corporation. NASA Headquarters asked the Manned Spacecraft Center to schedule a demonstration on 26 and 27 August. Schmitt and Don Lind were the test astronauts for the occasion, and Schmitt was not happy with the results. He said there was too much activity during the first period outside the spacecraft and there were no clear procedures for the second. At a review the next day, Apollo Spacecraft Program Manager George Low suggested that the first landing mission include only one walk on the surface. He listed priorities as he saw them: taking a sample of lunar material in the immediate vicinity of the

CHARIOTS FOR APOLLO

lander, inspecting and photographing the vehicle to make sure everything was in order, gathering at least one box of selected lunar surface soil and rocks, and setting up either a "partial ALSEP" or an erectable antenna and a television camera. Low proposed that the planned field geology investigation be eliminated.¹⁹

Apollo Program Director Samuel Phillips, from Headquarters, had realized after watching the demonstration that plans for the lunar surface walk would need close attention and some sensible decisions. He asked Houston Director Robert Gilruth to poll that center's key leaders and forward their views so Mueller's management council could study the pros and cons of the proposed surface activities. At that time, Rose reported to his flight operations planning group on 30 August, the first landing mission had two flight plans. The first called for one crewman to leave the lander (although both would have the equipment for surface expeditions) and the deletion of the experiments package; the second plan required both the commander and the pilot to get out and set up the six experiments in the package. Houston knew that Phillips favored sending only one man out on the moon, but Gilruth wanted both crewmen to go, so they could assist each other, if necessary. Gilruth's managers also suggested deleting both the experiments package and the lunar geology investigation.²⁰

Phillips passed Houston's recommendations on to the council, with the reminder that descent, landing, and ascent maneuvers were new tasks and that the astronauts needed all the training they could get. Eliminating the experiments package would give them an additional 180 hours to train for the more basic chores. Gemini experience had demonstrated the wisdom of proceeding step by step, with very light workloads on the early flights leading to more crowded schedules in later missions. This plan would mean a very small return in scientific data from the first lunar landing and would invite criticism from the scientific community. Wilmot Hess, in Houston, was already urging that at least some easily handled contingency experiments be included.

Phillips also told the management council of Houston's preference for a single period of exploration outside the spacecraft. Although he still did not agree that both pilots should get out, he conceded that more data would be gained from the interaction of two men with the lunar surface. Phillips added that the psychological effect on a crewman of landing on the moon and then being forbidden to step out on the surface must be considered. In its October meeting, the council approved the use of a scaled-down experiments package—an "early Apollo scientific experiments package"—consisting of two subpackages: one containing a passive seismic experiment, a solar cell array, an antenna, and two plutonium heaters; the other, a laser ranging retroreflector.²¹

Apparently the council sided with Houston in its views on activities outside the lander, because the center began planning for a two-man ex-

TO LAND ON THE MOON

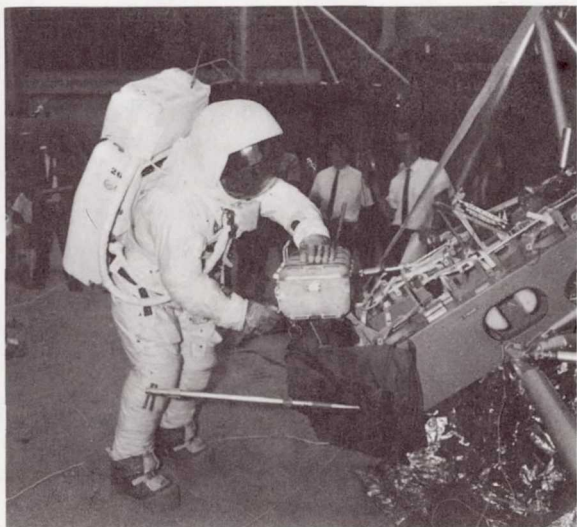
ploration at a mission review meeting on 1 November. The second astronaut would disembark after the first had been on the surface for an hour, and the total time outside would be three hours. Low asked his engineers to make sure that the control center was prepared to watch over the lander's systems while both men walked on the moon.

When Houston began work on the two-man scheme, the planners used a 1964 concept that called for the lunar module pilot to emerge first. Armstrong and Aldrin began concentrating on Apollo 11 as soon as they finished their backup duties for *Apollo 8* in December. Almost immediately, on the 20th, a procedures document listed the commander as the first crewman to leave the lunar module. On a summary minute-by-minute work chart, issued in January 1969, the crew positions—commander and lunar module pilot—were crossed through and the letters A and B were penciled in. A lunar surface operations chart, using these letters, was then published, but without any identification of either A or B.²²

Collins wrote in *Carrying the Fire* that Armstrong had “exercised his commander’s prerogative” and that Aldrin’s “basic beef” was this switch in who crawled out first. But Slayton later took the credit (or blame) for making the change. “I observed the procedures under the old plan one day,” he said, “and they appeared awkward to me.” Slayton told Raymond G. Zedekar, in charge of preparing a lunar surface operations plan, to change



Aldrin (left), lunar module pilot for Apollo 11, sets up a solar wind experiment during a practice session. Mission commander Armstrong, opening a lunar sample box, rests it on the lunar module’s modular equipment stowage assembly (MESA) hatch.



CHARIOTS FOR APOLLO

the sequence. At the 15th lunar surface operations planning meeting on 14 February, Zedekar said that Aldrin would follow the commander to the lunar surface in less than the hour listed in the old plan, to assist Armstrong with the outside tasks, and that the lunar module pilot would return to the lander first. "If the CDR returns last," Zedekar remarked, "the crewmen will be in their proper respective positions in the LM." Since the portable life-sustaining backpacks were stored directly behind the lunar module pilot's crew station, getting out and then back in this sequence made crew movements in the cabin easier.²³

Surprisingly, Mueller did not inform Administrator Thomas Paine* that the two men would take a 2-hour 40-minute walk, nor did he tell him that the order of exit had changed, until 7 April—at least, that was the date of his written report. Even more surprising was the fact that it was not until 14 April that a newsman asked Low, "Who will be the first out to the moon?" Low replied that, from "the present way that we're working, . . . the Commander gets out first." The change later roused a small furor. Low was awakened in the middle of the night on 27 June by a call from an Associated Press reporter, who told the Apollo manager that the wire service had a story "that Neil Armstrong had pulled rank on Buzz Aldrin." (Armstrong, incidentally, was a civilian and Aldrin a colonel in the Air Force.)^{† 24}

Regardless of crew sequence, training was going to be rough. Although the scope of the mission had been reduced, many still wondered whether the astronauts could be ready by July. Until James McDivitt got his *Apollo 9* crew off on its mission in early March, Armstrong's group had only third priority on the training simulators. Armstrong might have used the time to sharpen his lunar module piloting skill, but the lunar landing training vehicle—the apparent cross between a Rube Goldberg device and a child's tinker toy machine that was called by some observers the "flying bedstead"—had been grounded. The Apollo 11 commander himself had ejected safely from a similar vehicle just before it crashed on 6 May 1968. Soon after completing that accident investigation in November, Joseph S. Algranti, head of Houston's Aircraft Operations Office, had bailed out of another crashing trainer on 8 December. The accident board reconvened, presenting its findings in mid-February 1969. Some of NASA's top officials thought the crew could get sufficient training on the static simulator and on the tower suspension facility at Langley. But the astronauts and their support personnel insisted that this free-flight vehicle was essential to provide the experience they

* Paine was no longer "Acting" head of the agency. On 5 March 1969, President Nixon had nominated him as Administrator, and on 3 April Vice-President Agnew had sworn him into office.

† Low informed the Public Affairs Officer in Houston that "the basic decision was made by my Configuration Control Board . . . based on a recommendation by the Flight Crew Operations Directorate. I am sure that Armstrong had made an input to this recommendation, but he, by no means, had the final say. The CCB decision was final."

needed before flying the last 150 meters to the lunar surface.²⁵

In March, after two sessions, the Flight Readiness Review Board decided to resume the training flights. Harold E. Ream, who had flown these machines 35 times, was ready to put the trainer through a dozen hops in early April. Mueller agreed to let Ream test the craft but, he told Gilruth, he wanted another evaluation before any astronauts flew it. The next month, Slayton summarized for Gilruth and his top staff the aerodynamics and handling characteristics of the trainer, which had been modified to overcome its unstable tendencies. Gilruth's group was satisfied, and Mueller consented to the resumption of astronaut flights. During three consecutive days—14–16 June (eight times on the final day)—Armstrong successfully rehearsed lunar landing operations with the free-flight machine.²⁶

Although practicing the landing was critical, the crewmen did not stand around and wait to fly the trainer. They had plenty of other work to do. Armstrong and Aldrin polished procedures for their lunar surface activities, and they watched with keen interest the final push to qualify the extra-vehicular garb and life-sustaining systems. Collins, meanwhile, concentrated on those 18 rendezvous recipes in his cookbook, learning how to cope with all the different situations that the simulator personnel dreamed up to test his abilities.

In an attempt to simulate lunar surface conditions, Max Faget's group set up a model of the lander in a thermovacuum chamber in Houston. The chamber was not big enough for the pilots to move a hundred meters away from their craft as they planned to do on the moon, but the engineers did provide the desired lighting—a 15-degree sun angle—and the proper temperature range. The crew crawled out of the lander, pulled a package from the MESA (modular equipment stowage assembly) section in the descent stage, and deployed the experiments. During one of these sessions, Armstrong had to report: "Mission Control this is Apollo 11, we can't get the hatch open." ²⁷

While the chamber tests were going on, two dozen engineers, mostly from Faget's directorate, held monthly meetings on the status of the extra-vehicular mobility unit. James Chamberlin, one of the nation's top space vehicle and equipment designers, led the group, which operated much as Rose's flight operations planning team did. The Design Review Board studied the system, piece by piece, and then assigned Crew Systems Division specialists to work on specific problems and submit their resolutions for board approval. For example, Thomas Mattingly, the astronaut representative on the board, reported that the reflective gold coating on the helmet visors peeled after several cleanings with solvent, allowing light to leak through.

Another area under study was how well the crew could grasp lunar samples with gloved hands. During a chamber run, the systems people coated one of Armstrong's gloves with silicone and left the other uncoated. Armstrong reported that the treated glove worked better, and the board ap-

CHARIOTS FOR APOLLO

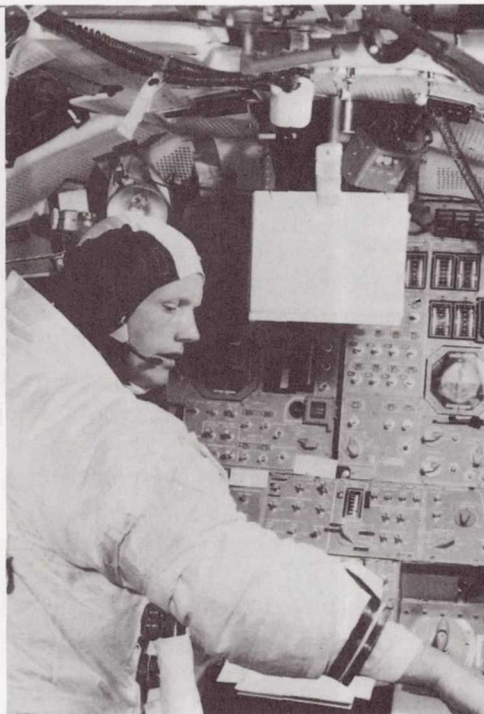
proved the change, which upset the scientists. Hess complained that the silicone would contaminate the lunar samples and pointed out that his group would have enough trouble with contamination by the fumes from the descent engine exhaust and the attitude thruster fuel. "Can't we get rid of [the silicone]?" Reminding Hess that time was too short to look for a substitute, Low refused. Crew Systems Chief Robert E. Smylie added that silicone was basically inorganic and that the tips of the glove fingers and the lunar boots were already made of that substance, so coating the gloves should not make much difference.²⁸

Chamberlin's board also investigated suit fit and mobility. In chamber sessions on 27 March and 7 April, Armstrong complained that his sleeves were too tight and asked that some of the bulky material be removed from inside the elbow. When he bent his arms, he said, some of his capillary blood vessels ruptured. Aldrin, too, wanted adjustments, such as shorter suit arms. There was some discussion about how hard it would be to walk on the lunar surface wearing the big 85-kilogram pack on their backs—even though the moon had only one-sixth the earth's gravity. Using Don Lind as a test subject, Crew Systems discovered that there would be a small shift in the center of mass. The crewmen could compensate for this by leaning slightly forward. If they bent over too far, however, they might overbalance and fall.²⁹

Throughout the training period, people worried about the crew's moving around on the moon. In March 1969, Phillips wrote Low that it bothered him that there was no way to measure energy expenditure or carbon dioxide production during the lunar walk. Low replied that the measurements already planned—oxygen and water consumption and heart rates—would tell what was happening and the systems monitors would watch the display indicators very closely.³⁰

In February 1969, NASA officials decided to construct a one-sixth gravity simulator in the centrifuge building to get a closer look at lunar locomotion. A pathway, with a simulated lunar surface, around the periphery of the 46-meter-diameter rotunda would provide a walkway of unlimited length. Dressed in full regalia and with umbilical lines attached to the instruments inside the centrifuge checking biological and metabolic data, an astronaut, suspended by a harness that would bear all but one-sixth of his weight, could practice for walking and working on the lunar surface. Since the simulator was completed too late in their training to be of much use to the Armstrong crewmen and since they did not plan to venture as far away from the lander as later crews, Armstrong and Aldrin would check out and evaluate the facility after their flight rather than before. Physicians were getting some of the desired data during underwater training (where locomotion was similar to that experienced in space) and in KC-135 aircraft Keplerian trajectories (which duplicated weightlessness for a few seconds at the top of the flight arc).³¹

During February, Mueller asked Gilruth to hold a lunar surface dem-



Training for Apollo 11: Collins (above) practices tending the command module alone; on the mission, crewmates Armstrong and Aldrin will leave him in lunar orbit and descend to explore the moon's surface. Armstrong (right) practices in the lunar module simulator. To train for walking on the moon, a harness (below left) rigged to support all but one-sixth of a man's weight was used by nearly all the astronaut corps. For several years they also trained on the lunar landing training vehicle. (below right) at Langley Research Center, to simulate landing the lunar module.



onstration similar to the one given in August 1968. Gilruth arranged the exhibition for the latter part of April 1969, and Phillips' Certification Review Board would study the exercise to check on the status of that part of the mission. An extravehicular activity committee set up by Gilruth under

CHARIOTS FOR APOLLO

his special assistant, Richard S. Johnston, had already conducted many reviews of the plans, procedures, and equipment. Mueller was pleased with the session, telling Paine that the simulation was smooth and the crew was "ready for the first lunar landing." Phillips was disturbed when the demonstrators used a rope pulley to haul equipment and samples up and down from the cabin to the surface and back. He suggested that the astronauts carry the materials in one hand. Low explained that the first rung on the ladder was 65 centimeters from the surface, and the crewmen could lift their legs only 30 centimeters with any ease. The astronauts would have to hop or pull themselves up, using both hands, which they had done successfully in water and on KC-135 aircraft. By the end of June, the final version of the lunar surface operations plan was completed.³²

Armstrong and Aldrin also trained at other places, especially at Langley Research Center, where they worked on the suspended lunar landing trainer equipped with realistic surface views and lighting. On 12 June, NASA senior management agreed that the crew was ready for a 16 July launch. Less than a month later, on 7 July, Mueller told Paine that "if Apollo 11 continues to progress on plan, the first men will set foot on the moon two weeks from today."³³

AFFAIRS FOR THE PUBLIC

The coming flight of Apollo 11 captured more worldwide attention than any previous mission. Countless numbers of persons tried to identify with, seek a meaning for, and fashion or obtain some keepsake of mankind's first visit to a celestial neighbor. These desires were expressed in poetry, in prose, in symbolic articles, and in pictorial evidence. Whole issues of journals, sections of newspapers, brochures, television and radio specials, books, bric-a-brac, stamps, medallions, photographs, pieces of clothing, record albums, and magnetic tape records commemorated the occasion. Some persons made suggestions, some bluntly demanded a piece of the moon, and some sought to get as close as possible to the launch and flight control sites. Most of the millions relied on radio, television, and newspapers for a firsthand account of the manned lunar landing experience.

NASA officials moved carefully and deliberately in meeting the demands brought on by Apollo 11. Early in 1969, Julian Scheer, Assistant Administrator for Public Affairs in Washington, wrote Gilruth, stressing past policy and operational philosophy. The agency, Scheer said, did "not seek coverage of space but [would] break our backs making our facilities and our people available," with "no free rides, no free meals, no glad-handing."

The crux of Scheer's letter was his determination to get Gilruth's Public Affairs Officer, Paul Haney, out of a dual role as full-time mission commentator and as supervisor of the whole range of public affairs activities in

Houston. When Scheer first came to NASA in 1963, he found that John A. Powers appeared to be favoring the television industry in the coverage of Mercury events; Scheer also disliked the identification of Powers as the "Voice of Mercury Control." The Headquarters leader sent Haney to Houston to replace Powers. In the ensuing years, although he trained a team of mission commentators, Haney seemed to be emulating Powers, becoming known as the "Voice of Gemini" and then moving into a similar role for Apollo. Scheer then gave the Houston public affairs leader the choice of remaining as mission commentator or confining himself to his duties as head of the Public Affairs Office. When Haney chose the former, Scheer changed his mind. He asked Gilruth to transfer Haney to Washington. Instead, Haney resigned. Scheer then sent Brian M. Duff from Headquarters to run the Houston activities. Duff did not talk from "Apollo Control" at all. The new voice became voices—John E. McLeaish, Terry White, John E. Riley, and Douglas K. Ward—from the public information section of Houston's Public Affairs Office.³⁴

Scheer then turned to another objective—making the Apollo 11 astronauts more available to the news media than past crews had been. He wanted the public to see the pilots as human beings, to foster a better understanding of their training and goals. In a letter to Slayton, Scheer warned that there would be changes. The practice of allowing one stilted crew press conference with each network, for a limited time and in sparse surroundings, had presented the astronauts as stereotypes. Scheer wanted each crew member to spend at least a full day with each of the networks, with the wire services participating, in backgrounds selected by the media. If, for example, they wanted the commander in Ohio, his home state, then he should go to Ohio and give the reporters a more intimate glimpse of Armstrong, the man, rather than Armstrong, the space flight technician. Scheer asked for more time with the astronauts for still and motion pictures. He also suggested that the wives of the Apollo 11 crews might attend a tea given for the women of the press corps. Scheer reminded Slayton that the networks, on occasion, would cover the mission for 24 hours at a stretch and would need many human interest stories as fillers. The public would be better able to share in the ventures of these men on the moon if it knew who they were, why they were there, and what they were doing, a knowledge that could be achieved only through more time with the men and better training documentation, films, and taped reports of the progress to the launch.³⁵

Slayton gave in on a few points—some parts of training, for example—but dug in his heels on the other demands. "Homes and wives are personal," he snapped, "and landing on the moon does not change that." Slayton remarked that he did not think any "hard sell" was necessary for Apollo 11, adding that "one rose does not make a summer (or something like that)." He went on, "This is just another mission which *may* land on the moon first, but definitely will not go anywhere on schedule if we cannot keep the

CHARIOTS FOR APOLLO

crew working instead of entertaining the press.”

Scheer did not give up, however. Low wrote Gilruth that 30 members of the press would attend a rehearsal of the lunar surface extravehicular demonstration requested by Headquarters on 18 April; but there would be no news coverage of the formal session four days later. Scheer fought that decision and won. Phillips notified Low that Mueller and Scheer had agreed to let a five-man news media pool watch the formal session. In May, Slayton and Duff worked out an understanding for more extensive reporting of various phases of training. And on 5 July, only 11 days before launch, the crew talked with the press about the mission. Armstrong, Collins, and Aldrin were shielded from other than visual contact by a plastic booth, to preserve the integrity of their prelaunch quarantine, but the “armor” had been pierced.³⁶

Scheer also suggested that top-level officials from both Headquarters and the field elements—most of whom were more used to writing memoranda, notes, and papers for technically oriented audiences—participate in drafting articles directed at the public for a *New York Times* project. In April, he asked these managers to make out invitation lists for the next two launches and to choose a cross-section of guests who had no direct connection with aerospace activities and who had never seen a launch.³⁷ With the approach of Apollo 11, Scheer assumed a stronger, more aggressive role in NASA's public affairs, and he used the pressures of the mission as a lever to get the agency to accept his thinking.

One item of worldwide public impact—television—raised no issues whatsoever on this flight. Slayton even urged the need for some kind of erectable antenna. The crewmen could not, after all, be expected to wait patiently in the lander until the earth moved Goldstone, California, and its 64-meter radar dish into line with the spacecraft—before they climbed out onto the surface. There was also some question whether the Goldstone facility would be available, since it was needed for a Mariner flyby of Mars in July. At a management council meeting in March, the prospect of doing without the big California dish, as well as a similar one at Parkes, Australia, forced agreement on a contingency plan for a portable antenna. Eventually, both Goldstone and Parkes were free to cover Apollo 11, but proper alignment with Goldstone was still a problem. Low decided to delay the lunar module's descent by one revolution to make sure “that we will have Goldstone coverage.” If the launch was delayed and if Parkes was better situated to pick up the signals, the relay would travel from the lunar module to Parkes, to Sydney by microwave, across the Pacific Ocean via synchronous satellite *Intelsat III*, to the control center in Houston, to the television networks, and thence to television sets throughout most of the world. Goldstone would shorten that route.³⁸

Some Apollo managers were worrying about the quality of the pictures they could expect. Looking at a photograph of a simulation, Phillips ob-

served to Low that the first step onto the lunar surface might be in the shadows. And the light might be too bright in the stowage area, as the astronauts unloaded the experiments package. Phillips asked Low to see about this, since "sharing with the world our historical first steps onto the moon warrants our efforts to maximize this return." Low did not believe the results would be as bad as Phillips feared, but Houston set up scale models under various lighting conditions to make sure of good coverage of the crewman as he descended to the lunar surface. Before he left Houston, Paul Haney had suggested that the surface camera be set up to photograph the liftoff from the moon. The idea was exciting, but it was too late to arrange it for Apollo 11. It would have to wait for a future mission.³⁹

Color television was so effective on *Apollo 10* that it was adopted for the following mission, but only in the command module. Faget was more than mildly upset when he learned that so much of the television, motion, and still photography planned for Apollo 11 would be in black and white. To him, it was "almost unbelievable" that the culmination of a \$20-billion program "is to be recorded in such a stingy manner." Low explained that some of the scientists insisted on black and white film, because it had a higher resolution than color film. Furthermore, with no atmosphere to absorb the solar energy in the ultraviolet, color film might not turn out well on the lunar surface.⁴⁰

In January 1969, NASA began work on plans to commemorate Apollo 11 symbolically. Phillips wrote Gilruth, Wernher von Braun, and Kurt Debus that ideas discussed at Headquarters included planting United Nations and United States flags, putting decal flags of U.N. member states on the lunar module descent stage, and leaving a capsule on the surface with information about the Apollo program and personnel and copies of international agreements. Gilruth asked Johnston to canvass the top Houston staff for suggestions. The consensus was that the American flag should be raised in a simple ceremony. This proposal was supported by private citizens from East Coast to West. Slayton said the pilots would probably carry personal items, as had been done in the past, but most of these would be brought back. All they intended to leave on the lunar surface, besides the descent stage, would be such things as the experiments, backpack, and lunar overshoes. Slayton added that he had no objection to anything that might be decided on as a symbol of the mission, but it must meet weight and stowage requirements and place no additional training demands on the crew.⁴¹

Paine assigned Associate Deputy Administrator Willis Shapley as chairman of a committee* to draft recommendations. Shapley's group met for

* The committee comprised Homer Newell, Mueller, Lieutenant General Frank A. Bogart (alternate), Phillips, Thomas E. Jenkins (alternate), Gilruth, Johnston (alternate), von Braun, Debus, Paul G. Dembling, Scheer, Arnold W. Frutkin, and James L. Daniels, Jr. (secretary).

CHARIOTS FOR APOLLO

the first time on 1 April and considered three categories: articles to be left by the astronauts (flag or flags, commemorative plaque), articles to be attached to the descent stage (inscriptions, documents, microfilm), and articles to be taken to the moon and brought back (photographs, flags, stamp dies, tokens). The chairman reported that Scheer and Assistant Administrator for International Affairs Arnold W. Frutkin were working out words for a plaque. Shapley also said that suggestions were being solicited from the Smithsonian Institution, the Library of Congress, the Archivist of the United States, the NASA Historical Advisory Committee, the Space Council, and congressional committees. The flag proposal was the most persistent. There were also discussions about carrying miniature flags of all the United Nations in a metal box shaped like a pyramid (but not the official flag of the United Nations or any other organization). The aim of the whole committee was to make it clear that, regardless of the symbol chosen, the United States had landed on the moon first.⁴²

Shapley's committee released its decisions on 2 July. Only the flag of the United States would be unfurled and left on the moon. Miniature flags of all the United Nations, the United States, its 50 states, its territories, and the District of Columbia would be stowed in the lunar module and returned to the earth. Other items to be brought back included a stamp die, a stamped envelope (to be canceled en route by the crew), and two full-sized United States flags that had flown over the two houses of Congress (to be carried in the command module). Personal items would be carried by the pilots in their kit bags, after approval by Slayton.

Two important items besides the flag were to be left on the moon. One was a microminiaturized photoprint of letters of good will from representatives of other nations. The other was a plaque affixed to the descent stage as a permanent monument, to be unveiled by the crew. It would depict the earth's two hemispheres, their continents and oceans, but no national boundaries. Bearing the words "Here men from the planet earth first set foot upon the moon. We came in peace for all mankind," it would be inscribed with the signatures of the three astronauts and the President of the United States. To forestall any charges that the United States was attempting to establish sovereignty over the moon, Robert F. Allnutt, NASA's Assistant Administrator for Legislative Affairs, prepared a statement containing the gist of a 1967 treaty governing all space exploration. The United States, one of the 89 signatories, had no intention of claiming the moon.⁴³

Suggestions for honoring the landing, on both the moon and on the earth, came from throughout the country. One person thought the plaque should be inscribed with the names of the astronauts who had lost their lives during the program, one argued that the carrier *John F. Kennedy* should recover the crew after the journey, one suggested that a complete Apollo-Saturn stack be erected in the style of the Washington monument

TO LAND ON THE MOON

in the nation's capital, and one recommended that the ashes of recently deceased space author Willy Ley be placed on the moon.⁴⁴

Collins mentions in his book that two of their "non-technical chores [were] thinking up names for our spacecraft and designing a mission emblem." Scheer had cast a jaundiced eye on the call signs selected by the crews of McDivitt and Thomas Stafford. He urged Low to make sure those chosen for the lunar landing, "to be witnessed by all mankind," were more appropriate. Low and Armstrong agreed that the names should not be frivolous. At the end of May, Slayton submitted a patch, which Headquarters turned down. It depicted an eagle (an obvious name for the lander) carrying an olive branch in its beak and descending to a lunar landscape, with "Apollo 11" at the top of the emblem. Headquarters thought the eagle's extended talons looked menacing. Although shifting the olive branch from the beak to the claws presented a more reassuring aspect (and won Headquarters approval), Collins facetiously wrote that he hoped the eagle dropped that branch before he touched down. Collins had his own problems in choosing a name for the command module. He was still wrestling with the task in mid-June. He credits Scheer with suggesting the name "Columbia."⁴⁵ So the ceremonies and symbols of Apollo 11 were finally set.

Plaque on the landing gear of the Apollo 11 lunar module. The descent stage would remain on the moon, a permanent commemoration of the first visit at the landing site.



CHARIOTS FOR APOLLO

DOWN TO THE WIRE

Mission planning and crew training were only two of the many activities that had to be carried out for Apollo 11. NASA and contractor employees worked out procedures and prepared facilities for handling and studying lunar samples, drafted recovery plans for both the crew and the moon materials to calm fears of back contamination, and tested the lunar module. And review piled on review as preparations for Apollo 11 came into the home stretch.

John E. Pickering, NASA's Director of Lunar Receiving Operations, reminded Hess in September 1968 that there were only 300 days in which to get ready for the mission—and weekends and briefings would chew up more than a third of that time. Pickering outlined a schedule of month-by-month activities that would have to be carried out if the receiving laboratory was to meet the deadline. Gilruth set up an operational readiness inspection team* in October, headed by John Hodge, to check out the laboratory. In January 1969, Phillips added this Houston facility to the other items that would be reviewed by the certification board. He named five major aspects for study: landing and recovery procedures, laboratory operations, astronauts and samples release plans, sample processing and distributing plans, and scientific investigations. Gilruth set the review for 3 February, with an agenda that included briefings on all activities from the time the astronauts landed on the lunar surface until scientific results were reported.⁴⁶

The Lunar Receiving Laboratory covered 25 300 square meters. Public interest focused on the crew reception area, which served primarily as a quarantine facility for astronauts and spacecraft, with their attending physicians, technicians, housekeepers, and cooks. Scientists were more concerned with the sample operations section, where the lunar materials were analyzed, documented, repackaged, and stored within a biological barrier. The third, and final, area contained support and administrative personnel, laboratories, offices, and conference rooms. Employees who worked here, outside the barrier, were free to come and go—unless they accidentally came into contact with the lunar materials or the astronauts. In February these teams went through a six-week rehearsal of the events that would take place from the arrival of the moon rocks to the end of the quarantine period. It was obvious that the laboratory teams were not ready. Gilruth sent Richard Johnston to take charge and to start a crash program to get the laboratory moving. Johnston ran practice tests of all laboratory

* Hodge's team consisted of Peter J. Armitage, Aleck C. Bond, John W. Conlon, D. Owen Coons, Joseph Kerwin, Paul H. Vavra, and Earle B. Young (MSC); E. Barton Geer (Langley); A. G. Wedum (Fort Detrick); and Donald U. Wise (NASA Headquarters).

procedures, insisting on participation by principal investigators assigned to the experiments, until he was satisfied that everything was in order.⁴⁷

Gilruth had asked Johnston in January 1969 to find out what the Houston senior staff thought was needed to prevent back contamination. To help this group in making judgments, Johnston set up briefings by specialists on landing and recovery, flight crew support, laboratory preparations and operations, and agenda summaries of coming meetings of the Inter-agency Committee on Back Contamination. In the meantime, Paine had turned over back contamination responsibilities to Mueller, who began discussions with representatives from the Departments of Agriculture and the Interior and the U.S. Public Health Service. These scientists visited the laboratory in mid-February and asked for tighter controls on even the most minute operations. In May, Gilruth established an Apollo Back Contamination Control Panel,* similar to the spacecraft configuration control boards, to conduct very strict reviews of any changes in either facilities or procedures.⁴⁸

A successful quarantine would depend on carefully worked out spacecraft, lunar sample, and crew recovery procedures. In November 1968, Washington asked Kraft's recovery operations people to conduct "an end-to-end dress rehearsal simulation." This test began in January when the Mobile Quarantine Facility, resembling a streamlined automobile house trailer without wheels and capable of supporting six persons for ten days, was passed between two ships near Norfolk, Virginia. About the time of the *Apollo 9* recovery, four test subjects made a trial run in the quarantine facility from the Pacific to Houston.⁴⁹

There were a few hitches in working out the recovery plan. Any contamination that the command module might pick up from the lunar module should be neutralized by the searing heat of earth reentry before the vehicle splashed into the Pacific. The planners intended to lift the command ship aboard the prime recovery vessel and park it next to the quarantine trailer, so the crew could move quickly into isolated quarters. This idea had to be abandoned because the attachment loop on the space vehicle was not strong enough—it could have pulled loose and dumped the craft, crew and all, into the sea. Crew system specialists then came up with what they called a biological isolation garment—BIG in the technicians' usual shorthand. The crew would climb from the spacecraft into a raft, put on the garments (which really made them look like creatures from outer space), ride a helicopter to the ship, deplane, and enter the trailer. Kerwin and Collins tested the garments in a tank and discovered that the face mask filled with

* The panel consisted of Johnston (chairman), Walter W. Kemmerer, Jr., Persa R. Bell, R. Bryan Erb, Bennie C. Wooley, John C. Stonesifer, James H. Chappee, and Herbert L. Tash (secretary).

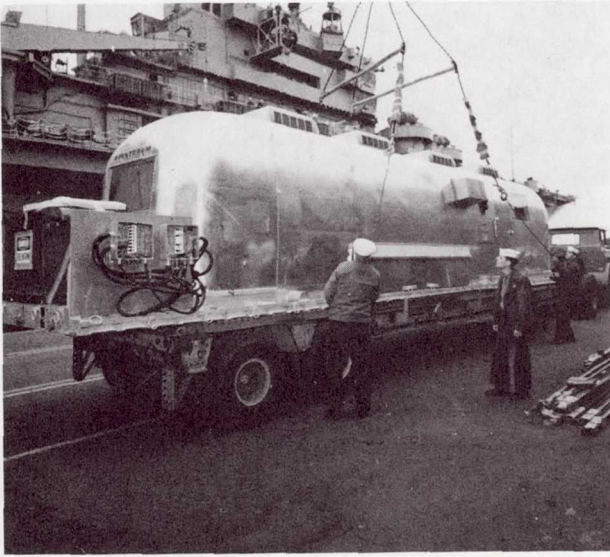
CHARIOTS FOR APOLLO

water when the inhalation valve was submerged. If rough seas dumped the crew from the raft, the biological barrier would be broken when they pulled off the masks to keep from drowning. But this problem was corrected, procedures were impressed on the crew of the carrier *Hornet*, details were cleared with the Interagency Committee on Back Contamination, and a notice was published in the Federal Register. On 26 June, Kraft notified everyone concerned that procedures for recovery and quarantine were ready.⁵⁰

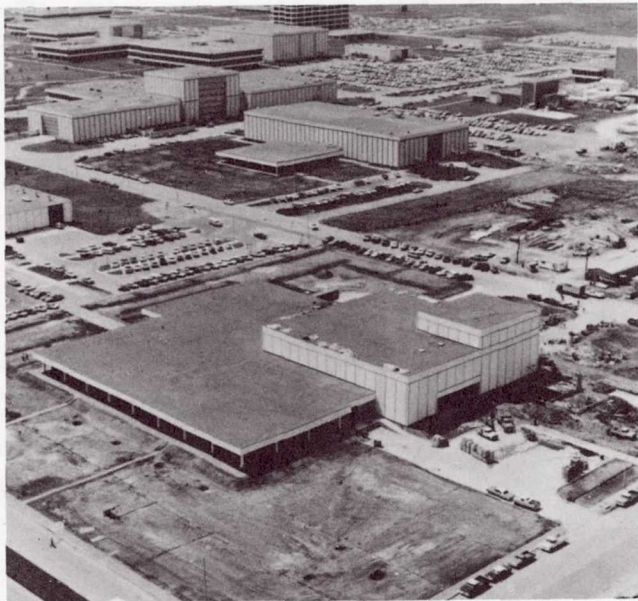
The lunar module probably had to undergo the toughest tests and the sharpest scrutiny of all the hardware, procedures, and facilities. LM-2, veteran of the Saturn launch vehicle pogo testing program, was called upon to simulate landing stresses. Robert J. Wren, from Faget's directorate, and a team from Houston and Grumman rigged the vehicle in Houston's vibration and acoustic testing facility. Dropping LM-2 at slightly different angles to see how it would stand the shock of landing was a simple test. But the ascent stage carried a full propellant load and the descent tanks a small quantity of fluid; when the tanks were pressurized, this could be dangerous. Maximum safety precautions were taken, however, and the tests were completed successfully.⁵¹

Although the lander passed all its trials with good marks, Low still worried about single-point failures that could wreck a mission. He sent a "walk-down team" to the contractors' plants to inspect both spacecraft and told Rocco Petrone that he would like the same kind of inspection at the Cape by veterans in spacecraft flight preparations. Low even wanted someone to take a look at the landing gear to make sure the honeycomb shock absorbers had been installed.⁵²

Most of the flight readiness reviews for Apollo 11—mission content, lunar module, command and service modules, government-furnished equipment (the extravehicular pressure garments and backpack, experiments and equipment, and cameras), back contamination, and medical status—were held from middle to late June. Carroll Bolender, Houston manager of LM-5, found that the general quality had consistently improved, but the vehicle had more items for resolution on 23 June than LM-4 had at a comparable time. Martin Raines' flight safety team attended the reviews, keeping a close watch on the hardware, and admitted that the only great risk it could see was that Apollo 11 was to make the first lunar landing—and that risk would be there no matter what vehicle made the trip. The Boeing Company also reviewed the mission and came to the same conclusion. The missions were coming so close together now that Mueller began to worry about possible fatigue overtaking the workers. When he wrote Gilruth of his concern, however, the gist of his message was "worry [along with me] but don't allow [it] to interfere with driving your staff at full throttle until . . . the Lunar Landing." And they did drive on. On 14 July, Director Phillips confirmed that Apollo 11 was ready for flight.⁵³



*Mobile Quarantine Facility
off-loaded from carrier Ran-
dolph during recovery re-
hearsal simulation before the
Apollo 11 mission.*



*Lunar Receiving Laboratory
at the Manned Spacecraft
Center, Houston.*

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14

Trip to Tranquility

1969: July

In the summer of 1968, a group led by John R. Sevier in Houston studied hundreds of possible lunar landing sites. A lot was involved in setting the lunar module down on the moon—keeping the vehicle stable; gauging surface slopes and boulder distribution; controlling forward, lateral, and vertical speeds during the final few seconds before committing to a landing; and finally cutting off the engine at the proper instant. The spacecraft was equipped to make an automatic, hands-off landing, but analyses of site survey photographs indicated that in such a landing the vehicle would overturn 7 out of 100 times. Sevier's group contended that a manually controlled touchdown by the astronauts faced better odds. Using a lunar surface model complete with craters and hills and illuminated to match a particular time and date, the analysts demonstrated that the pilots could recognize the high slopes and craters in time to fly over and land beyond them and that there would be enough fuel to do this. Many of the suggested areas were eliminated on the basis of these studies; the list of candidate sites was pared to five for Apollo 11. When Site 2, in the Sea of Tranquility,* was chosen for the target in the summer of 1969, a waiting world watched and hoped that the space team's confidence was warranted.¹

* Site 2 was on the east central part of the moon in southwestern Mare Tranquillitatis. It was about 100 kilometers east of the rim of Crater Sabine and 190 west southwest of Crater Maskelyne—latitude 0° 43' 56" north, longitude 23° 38' 51" east.

CHARIOTS FOR APOLLO

THE OUTWARD VOYAGE

On 16 July, the weather was so hot, one observer noted, that the air felt like a silk cloth moving across his face. Nearly a million persons crowded the Florida highways, byways, and beaches to watch man's departure from the earth to walk on the moon. Twenty thousand guests looked on from special vantage points; one,* leading a poor people's protest march against the expense of sending man to the moon, was so awed that he forgot for a moment what he came to talk about. Thirty-five hundred representatives of the news media from most of the Western countries and much of the eastern hemisphere (118 from Japan, alone) were there to record the mission in newsprint for readers and to describe the scene for television and radio audiences, numbering according to various estimates as many as a billion watchers.²

Neil Armstrong, Edwin Aldrin, and Michael Collins must certainly have realized the significance of their date with destiny, even though all three were seasoned space travelers. But the normal launch day routine was observed. Donald Slayton roused the crew out of bed about 4:00 in the morning. Nurse Dee O'Hara recorded a few physical facts, physicians made a quick check, and the astronauts ate breakfast. Waiting to help them into their suits when they finished was Joe Schmitt, the astronauts' launch-day valet for the past eight years. After they arrived at the launch complex, still another old friend and veteran from Mercury and Gemini days, pad leader Guenter Wendt, assisted them into the spacecraft seats. Armstrong crawled in first and settled in the left-hand couch. Collins followed him, easing into the couch on the right side. As they wriggled into position, were strapped in, and checked switches and dials, Aldrin enjoyed a brief interlude outside on the white room flight deck, letting his mind drift idly from subject to subject, until it was time for him to slide into the center seat. When the hatch snapped to, the threesome was buttoned up from one world, waiting for the Saturn V to boost them to another.³

A Saturn V liftoff is spectacular, and the launch of *Apollo 11* was no exception. But it didn't give the audience any surprises. To the three Gemini-experienced pilots, who likened the sensation to the boost of a Titan II, it was a normal launch. The 12 seconds the lumbering, roaring Saturn V took to clear the tower on the Florida beach did seem lengthy, however. At that point in the flight, a four-shift flight control team in Texas, presided over by mission director George Hage and flight director Clifford E. Charlesworth, assumed control of the mission. The controllers, and the occupants of the adjacent rooms crammed with supporting systems and operations specialists, had little to worry about. Unlike the three Saturn

* Dr. Ralph D. Abernathy.

Vs that had carried men into space previously, this one had no pogo bounce whatsoever. Collins and Armstrong had noticed before launch that the contingency lunar sample pouch on Armstrong's suit leg was dangerously close to the abort handle. If it caught on the handle, they could be unceremoniously dumped into the Atlantic. Although Armstrong had shifted the pouch away from the handle, they worried about it until they attained orbital altitude. Then the crew settled down to give the machine a good checkout. Armstrong found he could not hear the service module's attitude thrusters firing; but Charlesworth's flight controllers told him they were behaving beautifully.⁴

To Armstrong, Aldrin, and Collins, the real mission would not start until they went into lunar orbit and separated the lunar module from the command module. To constrain their emotions and conserve their energies, they had decided to spend the first part of the trip resting, eating, and keeping themselves relaxed. If their matter-of-fact behavior and conversation before they went charging off to the moon on a direct course were any indication, they succeeded. Armstrong and Aldrin became drowsy before the engine firing that thrust them onto the lunar path—translunar injection—although Armstrong did murmur a mild “Whew,” when it began. Aldrin casually observed that the S-IVB stage was a “tiny bit rattly,” and Collins uneasily eyed a camera overhead during the 1.3-g acceleration loads, even though he knew it was fastened down securely enough not to bang him on the head. Like their predecessors, they had the upside-down sensation for a while, and Collins, who had to get out of his couch to work with the navigation equipment in the lower bay, was careful to move his head slowly, to guard against getting sick. But none of the three had any physical problems.⁵

The trip to the moon was quite pleasant. The crewmen ate and slept well, lodging themselves comfortably in favorite niches about the cabin. What work there was to do they enjoyed doing. Collins loved flying the spacecraft—no comparison with the simulator at all, he said—when he pulled the command module away from the S-IVB stage and then turned around to dock with the lunar module. But he was miffed at having to use extra gas from his thruster supply; it was like going through a bad session on the trainer, he fumed. Armstrong was delighted that there was not one scratch on the probe. The command module pilot had a momentary scare when he unstowed the probe and noticed a peculiar odor in the tunnel, like burned electrical insulation—but he could find nothing wrong. They relaxed again and began taking off their suits. Armstrong and Aldrin were especially careful to guard against snags; their lives would depend on these garments in a few days.

Their path to the moon was accurate, requiring only one midcourse correction, a burst from the service propulsion engine of less than three seconds to change the velocity by six meters per second. Not having much

CHARIOTS FOR APOLLO

to do gave the pilots an opportunity to describe what they were seeing and, through color television, to share these sights and life inside a lunar-bound spacecraft with a worldwide audience. They compared the deeper shades of color their eyes could see on the far away earth with those Houston described from the television transmission. Aldrin, pointing the camera, once asked CapCom Charles Duke to turn the world a bit so he could see more land and less water. After one particularly bright bit of repartee, Duke accused Collins of using cue cards; but the command module pilot replied firmly that there was no written scenario—"We have no intention of competing with the professionals, believe me," he said. The crew also received a daily news summary, a tradition dating from the December 1965 *Gemini VII* mission. During one of these sessions, the crew learned the latest news on *Luna 15*, the unmanned Russian craft launched 13 July and expected to land on the moon, scoop up a sample, and return to the earth.* Several times thereafter the trio asked about the progress of this flight.⁶

On Saturday, 19 July, almost 62 hours after launch, *Apollo 11* sailed into the lunar sphere of influence. Earlier, television viewers in both hemispheres had watched as the crew removed the probe and drogue and opened the tunnel between the two craft. Aldrin slid through, adjusted his mind to the new body orientation, checked out the systems, and wiped away the moisture that had collected on the lunar module windows, while the world watched over his shoulder. The pilots were glad to get the tunnel open and the probe and drogue stowed a day early—especially Collins, who had worried about the reliability of this equipment ever since his first sight of it years before.

As the moon grew nearer and the view filled three-quarters of the hatch window, Armstrong discussed lunar descent maneuvers with the flight controllers. He was glad to learn that the service module engine had performed as well in flight as it had during ground tests. The last kilometers on the route were as uneventful as the first. The pilots maintained their mental ties with the earth, enjoying the newscasts radioed to them and the knowledge that their own voyage was front page news everywhere. Even the Russians gave them top billing, calling Armstrong the "czar" of the mission. (At one time, when flight control called for the commander, Collins replied that "the Czar is brushing his teeth, so I'm filling in for him.") Had

* *Luna 15* entered lunar orbit 17 July and made 52 revolutions of the moon before hard-landing on the surface. Unmanned *Luna 16*, launched by the U.S.S.R. on 12 Sept. 1970, soft-landed with an earth-operated drill and returned a recovery capsule containing a cylinder of lunar soil to the earth on 24 Sept. Senate Committee on Aeronautical and Space Sciences, *Soviet Space Programs, 1971-75*, Staff Report prepared by Congressional Research Service, Library of Congress, vol. 1, 30 Aug. 1976, pp. 145-49.

TRIP TO TRANQUILITY

the news copy been available to them, they could have read it without difficulty by the light of the earthshine.

A day out from the moon, the crewmen saw a sizable object out the window, which they described variously as a cylinder, something L-shaped like an open suitcase, an open book, or even a piece of a broken antenna. All three believed that it had come from the spacecraft. Collins at first said he had felt a distinct bump; after thinking it over, he decided it must have been his imagination—the modular equipment stowage assembly in the lunar module descent stage had not really fallen off. Or had it? Whatever it was, it was interesting; the crew talked quite a bit about it after returning to earth.

IN LUNAR ORBIT

Seventy-six hours after leaving the earth, *Apollo 11* neared its goal. CapCom Bruce McCandless gave the crew the usual “see you on the other side,” as the spacecraft went behind the moon. Looking at the surface, Collins said it looked “plaster of Paris gray.” Like earlier commanders, Armstrong had to remind his crew not to look at it because they had to concentrate on the first lunar orbit insertion maneuver to get into a nice elliptical flight path. The astronauts agreed that changing sun angles produced different shades of gray and tan. Some of their descriptions of the back, as well as the front, of the moon were graphic. They also hoped no new meteors like those that had caused the lunar craters would fall while they were on the surface. Once Collins mentioned that the desolate Sea of Fertility had certainly been miscalled, and Armstrong gave him a short lecture on how it got its name. They shared the view of the near-earth side of the moon with television watchers back home. Pilots and observers alike could see that the planned landing area was still in darkness but getting brighter each time they flew over it. The astronauts commented that they certainly realized they were circling a smaller body than the earth, but they quickly became used to seeing “the moon going by.” Collins complained once that the “LM just wants to head down towards the surface,” and McCandless answered, “that’s what [it] was built for.” *

During the first two revolutions, the crewmen checked navigation and trajectory figures and then fired the service module engine against the flight path to drop *Apollo 11* into a nearly circular orbit. As they watched the landing area grow brighter and brighter, they rested, ate, slept, and re-

* The lunar module, which weighed more than the command and service modules combined, was feeling the pull of the moon’s gravity.

CHARIOTS FOR APOLLO

checked the lunar module systems. Because of the discussions, photographs, and motion pictures provided by the Borman and Stafford crews, the Armstrong team felt as though they were flying over familiar ground. Aldrin said that the view was better from the lunar module than from the command module.

At the beginning of the nine-hour rest period before Armstrong and Aldrin crawled into the lunar module and headed for the lunar surface, Collins urged his companions to leave the probe in the command module. Since this would shorten their preparations for the lunar descent, they were not hard to convince. They knew it would be wise to get as much rest as possible before they set out on that trip but none of the three slept as well as they had on previous nights—it was just not possible to dismiss the next days' momentous events from their minds. They were test pilots, but they were human.⁷

After breakfast on Sunday morning, 20 July, Armstrong and Aldrin floated through the tunnel and into the lunar module. Their preparations had been so thorough that they had little to do except wait for Collins to close off the two vehicles. Collins slipped the probe and drogue smoothly into place and then asked the lunar module crewmen to be patient while he went through the checklist. Feeling that he was part of a three-ring circus and appearing simultaneously in each ring, Collins raced around, setting cameras up in windows to photograph the separation, purging the fuel cells of excess water, and getting ready to vent the air pressure from the tunnel. On the back of the moon, during the 13th revolution, everything was ready, which gave him a short breather before the lunar module left. When he asked, "How's the Czar over there?" Armstrong replied, "Just hanging on—and punching [buttons]." Collins urged the lunar pilots to take it easy on the surface—he did not want to hear any "huffing and puffing." And so they parted, as Armstrong called out, "The Eagle has wings."

Armstrong and Aldrin began checking the lander's critical systems. One of these made everyone a little nervous. They had to turn off the descent stage batteries to see how those in the ascent stage were operating. If they were not working properly, every electrically powered system in the cabin would be affected. But the ascent stage performed beautifully. Next they fired the thrusters and marveled at the ease with which the *Eagle* flew in formation with *Columbia*. Aldrin turned on the landing radar, and it also worked properly. Collins broke in to ask them to turn on their blinking tracking light, and Aldrin replied that it was on.

Meanwhile, Collins found that the command ship was also stable. Sometimes the automatic attitude thrusters did not have to make corrections oftener than once in five minutes. Once his vehicle bucked when he inadvertently brushed against the handcontroller, but he quickly stilled the

TRIP TO TRANQUILITY

motion. Soon he reestablished contact with flight control and reported that the *Eagle* was coming around the corner.⁸

THE FIRST LANDING

Now the world could only listen and pray as it waited for the landing, which was not televised. The 12 minutes that it took to set the *Eagle* down on the lunar surface seemed interminable. After getting a go from flight control, Armstrong advanced the throttle until the descent engine reached maximum thrust, which took 26 seconds. Collins had seen the lander through the sextant from as far away as 185 kilometers, but he could not see it fire 220 kilometers ahead of him. Armstrong was not sure at first that the descent engine had ignited, as he neither heard nor felt it firing. But his instrument panel told him everything was in order. At 10-percent throttle, deceleration was not detectable; at 40- to 100-percent, however, there were no doubts. The lander was much more fun to fly than the simulator. Then, five minutes into the maneuver, the crewmen began hearing alarms. On one occasion, the computer told them a switch was in the wrong position, and they corrected it. Another time, they could find no reason for the alarm, but they juggled the switches and the clanging stopped.

Coping with these alarms, some of which were caused by computer overloads, lasted four minutes. Flight control was watching closely and passing on the information that there was no real problem with their vehicle. They could go on to a landing. But these nerve-wracking interruptions had come at a time when the crewmen should have been looking for a suitable spot to sit down, rather than watching cabin displays. They had reached "high gate" in the trajectory—in old aircraft-pilot parlance the beginning of the approach to an airport in a landing path—where the *Eagle* tilted slightly downward to give them a view of the moon. When they reached "low gate"—the point for making a visual assessment of the landing site to select either automatic or manual control—they were still clearing alarms and watching instruments. By the time they had a chance to look outside, only 600 meters and three minutes' time separated them from the lunar surface.

Armstrong saw the landing site immediately. He also saw that the touchdown would be just short of a large rocky crater with boulders, some as large as five meters in diameter, scattered over a wide area. If he could land just in front of that spot, he thought, they might find the area of some scientific interest. But the thought was fleeting; such a landing would be impossible. So he pitched the lander over and fired the engine with the flight path rather than against it. Flying across the boulder field, Armstrong soon found a relatively smooth area, lying between some sizable craters and another field of boulders.

CHARIOTS FOR APOLLO

How was the descent fuel supply? Armstrong asked Aldrin. But the lunar module pilot was too busy watching the computer to answer. Then lunar dust was a problem. Thirty meters above the surface, a semitransparent sheet was kicked up that nearly obscured the surface. The lower they dropped, the worse it was. Armstrong had no trouble telling altitude, as Aldrin was calling out the figures almost meter by meter, but he found judging lateral and downrange speeds difficult. He gauged these measurements as well as he could by picking out large rocks and watching them closely through the lunar dust sheet.

Ten meters above the surface, the lander started slipping to the left and rear. Armstrong, working with the controls, had apparently tilted the lander so the engine was firing against the flight path. With the velocity as low as it was at the time, the lander began to move backward. With no rear window to help him avoid obstacles behind the lander, he could not set the vehicle down and risk landing on the rim of a crater. He was able to shift the angle of the lunar module and stop the backward movement, but he could not eliminate the drift to the left. He was reluctant to slow the descent rate any further, but the figures Aldrin kept ticking off told him they were almost out of fuel. Armstrong was concentrating so hard on flying the lunar module that he was unable to perceive the first touch on the moon nor did he hear Aldrin call out "contact light," when the probes below the footpads brushed the surface. The lander settled gently down, like a helicopter, and Armstrong cut off the engine.

4 days, 6 hours, 45 minutes, 57 seconds. CapCom: We copy you down, Eagle.

Armstrong: Houston, Tranquility Base here. THE EAGLE HAS LANDED.

CapCom: Roger, Tranquility. We copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot.

And Armstrong started breathing again, too. He was not pleased with his piloting, but landing on the moon was much trickier than on the earth. He related the maneuver to his past experience in touching down during a ground fog, except that the moon dust had movement and that had interfered with his ability to judge the direction in which his craft was moving. Aldrin thought it "a very smooth touchdown," and said so at the time. They were tilted at an angle of 4.5 degrees from the vertical and turned 13 degrees to the left of the flight path trajectory. Armstrong agreed that their position was satisfactory for lighting angles and visibility. At first, a tan haze surrounded them; then rocks and bumps appeared. Man had landed successfully on the moon—and on his first attempt.⁹

TRIP TO TRANQUILITY

ON THE SURFACE

CapCom Charles Duke (Houston): "Good show." Command module pilot Michael Collins (*Columbia*): "I heard the whole thing." Commander Neil Armstrong (*Eagle*): "Thank you. Just keep that orbiting base ready for us up there." This three-way conversation was the first of a kind, coming from two ground stations (one on the earth, the other on the moon) and a craft in lunar orbit. When Armstrong stepped out on the surface, he and Aldrin would turn it into a four-way talk, using their backpack radios.

Flight control told lunar launch team Armstrong and Aldrin to begin the two-hour practice countdown. The duo liked working in the one-sixth gravity; it made the tasks seem light. And the checkout went well—the thruster fuel was only ten percent less than they had expected; but a mission timing clock had stopped, displaying a ridiculous figure that they could not correlate to any point in the mission. They tried to turn it back on. When they could not, they left it alone to give the instrument a chance to recover; flight control could keep track of the time in the interim. It soon became apparent that they were going to be able to stay on the moon and explore.

They wondered about their exact location, glancing out the windows and describing what they saw to give flight control and Collins some clues to aid in the search. While waiting to be found, Armstrong relayed all that he could remember about the landing. They knew they were at least six kilometers beyond the target point, although still within the planned ellipse. Colors were almost the same on the surface as from orbit: white, ashen gray, brown, tan, depending on the sun angle. Armstrong noticed that the engine exhaust had apparently fractured some of the nearby boulders. He glanced upward through the rendezvous window and saw the earth looming above them. They also heard via radio some unpleasant sounds from that planet, almost as though someone were moving furniture around in the back room. Flight control quickly silenced the racket, and the checkout on the moon continued.

Because they had adapted so easily to the one-sixth-g environment and because the simulated launch countdown had so few problems, Commander Armstrong decided to begin the extravehicular activity before the scheduled rest period. As Slayton had suspected, the astronauts could not just sit there. They wanted to get out and explore. Flight control agreed, adding that their movements would be watched on prime time television. Rigging up for the stroll took longer than during the training exercises on the earth, not because anything was wrong but because they took extra care to make sure that everything was right. About the only surprise they had was the discovery of a press-to-test button on the portable life support system that neither could identify. But they did not bother flight control about it; their backpack antennas were scraping the cabin ceiling, making communications

CHARIOTS FOR APOLLO

scratchy, and they had more important things to talk about. They were quite comfortable with the life support systems on their backs, which pleased them after their experiences in the earth's gravity. They did have to move carefully and methodically about the lander, however.

Finally, it was time to depressurize the cabin, open the hatch, and prepare to step out on the moon. Armstrong was wondering if the light would be good enough for the television camera to capture his first step, and he was thinking about the gymnastics of backing through the hatch and standing on the porch. Forty-five minutes after flight control had given the crew a go for depressurization, the cabin had still not quite reached a zero reading on the gauges, but it was close. The crewmen could not wait any longer; 6 hours and 21 minutes after landing, 20 July, they pulled the hatch open, and Aldrin watched carefully as Armstrong backed out. When he came too close to the sides of the hatch with his bulky backpack, Aldrin gave him detailed instructions—a little to the right, now more to the left—until he had safely reached the porch. Armstrong turned a handle to release the latch on the experiments' compartment and then went down as far as the footpad. He checked to see if he could get back up—that first rung was high. He did not expect any problems, although it would take a pretty good jump. Then the watching world saw what it had been waiting for—Armstrong's first step onto the moon.

"That's one small step for [a]* man, one giant leap for mankind."

With this historic moment behind him, Armstrong began to talk about the surface, about the powdery charcoal-like layers of dust, as he and the television camera looked at his bootprints in the lunar soil. One-sixth g was certainly pleasant, he said. He glanced up at the lunar module cabin, at Aldrin near the window. The lunar module pilot explained to the viewers what Armstrong was doing as he gathered the contingency sample and worked it into the pocket on his suit leg. Armstrong described the stark beauty of the moon, likening the area to the high desert country in the United States.

When Aldrin asked, "Are you ready for me to come out?" Armstrong answered, "Yes." The commander realized that extravehicular activity on the moon was a two-man job at the minimum. From his position on the ground, he could not give Aldrin as much help in clearing the hatch as he would like, but he did the best he could. On reaching the porch, Aldrin commented on how roomy it was; there was no danger of falling off. "I want to . . . partially close the hatch, . . . making sure not to lock it on my way out." Eighteen minutes and twelve seconds after the first man stepped on the

* Whether he actually uttered the article or not later caused considerable discussion. Armstrong, himself, later wrote: "I thought it had been included. Although it is technically possible that the VOX didn't pick it up and transmit it, my listening to the recording indicates it is more likely that it was just omitted."

TRIP TO TRANQUILITY

moon, he was joined by his companion. Aldrin also was struck by the "magnificent desolation." Although he could move easily, with no hindrance from the big backpack, he noticed that he did have to think about the position of the mass. Aldrin and Armstrong loped along, tried a kangaroo hop, and reverted to the more conventional mode of simply putting one foot in front of the other.* Despite the ease of movement, both explorers believed that hikes of two kilometers or more would be tiring. On the earth, they had to think only one or two steps ahead; on the moon, they had to work out five to six steps in advance. And the rocky soil was slippery.

In some ways, the astronauts felt frustrated on this first lunar outing; there was so much to see and do and so little time. They had planned some of their moves as they looked out the window before disembarking, but their field of view was limited to 60 percent of the area. This first landing may have been in what was supposedly a nondescript region of the moon, but even here they hoped that the cameras were capturing some of the detail they did not have an opportunity to investigate personally. Not being able to get down on their hands and knees to examine items closely annoyed them; but the powdery soil, its tendency to adhere to their clothing, and the difficulty of regaining upright positions in the bulky space suits dissuaded them from trying to kneel.

Shortly after Aldrin alighted, Armstrong unveiled the plaque on the leg of the LM, described the representation of the earth's two hemispheres, and read the words to a vast listening audience:

Here Man from the planet Earth first set foot upon the Moon, July 1969 A.D. We came in peace for all mankind.

Underneath were the crew members' signatures and the signature of the President of the United States (Nixon).

A little later they held the flag-raising ceremony. The telescoping flagpole stuck and they could not pull it out to its full extent; afraid that they might lose their balance and fall on the rocky surface, they did not try very hard. The ground below the surface was very hard, and they pushed the pole in only 15 to 20 centimeters. Flight control told Collins, circling in the command module above, of the ceremony, remarking that he was probably the only person around without television coverage of the event.

After another brief stint of evaluating their ability to move around, the crewmen were asked to step in front of the camera so the President could speak to them. President Nixon said, "I am talking to you by telephone from the Oval Room at the White House, and this certainly has to

* Armstrong even tried jumping straight up. When he noticed a tendency to pitch backward, he stopped.

CHARIOTS FOR APOLLO

be the most historic telephone call ever made." The President said America was proud of them and their feat had made the heavens a part of man's world. Hearing them talk from the moon inspired a redoubling of effort "to bring peace and tranquility to Earth. . . . For one priceless moment in the whole history of man, all the people on this Earth are truly one; one in their pride in what you have done, and one in our prayers that you will return safely to Earth."

All of the ceremonial episodes were short, the President's call was the last, and none used very much of the precious 2 hours and 40 minutes of the schedule.

The astronauts began the scientific part of their mission (see appendix D for experiment descriptions). Getting the science package from its stowage area was easier than in training and, although the kit had been close to the descent engine, no heat damage was observed. Aldrin elected to deploy the experiments manually and looked for level spots in which to set them up. He soon found that it was difficult to decide what was level ground by just looking at the surface. The laser reflector had a leveling device—a bubble, or "BB"—but Aldrin had trouble centering it. He finally gave up and went on to other tasks. Armstrong came over later to photograph the reflector, and the bubble was on dead center. They had no explanation for this. The commander wished he had some kind of a rock table on which to set the packages, to keep them from settling into the lunar soil, but there was no time for that kind of refinement. Aldrin set up the solar array experiment; one panel popped up automatically, but he had to pull on a lanyard with his gloved hand to get the other in place.

Time was getting short, so Aldrin left the experiments and began collecting the documented samples. Reminded by flight control that scientists wanted two core-tube specimens, he pushed the tube about 10 centimeters into the ground and began tapping it with a hammer. When it did not go much farther, he beat on it until the hammer made dents in the top of the tube. Even then he could only get it about five centimeters deeper. He pulled the sampler out of the ground, meeting little resistance. He had an impression of moisture in the soil, because of the way the material adhered to the tube. He tried again about five meters away, but the results were not much better. During the rapping and tapping, the seismic package transmitted the vibrations back to the earth.

Armstrong had been snapping pictures and filling sample boxes with lunar rocks and surface soil, describing what he was doing as he went from place to place. It took longer to gather the bulk samples than it had during earth simulations. He tried to keep as far from the engine exhaust blast area as he could. He operated the stereoscopic camera developed by scientist Thomas Gold, even though the trigger was difficult to pull with his gloves on. Once he wandered out about 100 meters, being careful not to get out of sight of the lander, to look at a crater and take some pictures. The trip took

TRIP TO TRANQUILITY

only a few minutes and was easy, but when he returned he wanted to stop and rest. Then he had to close the sample boxes, which took more effort than he had expected.

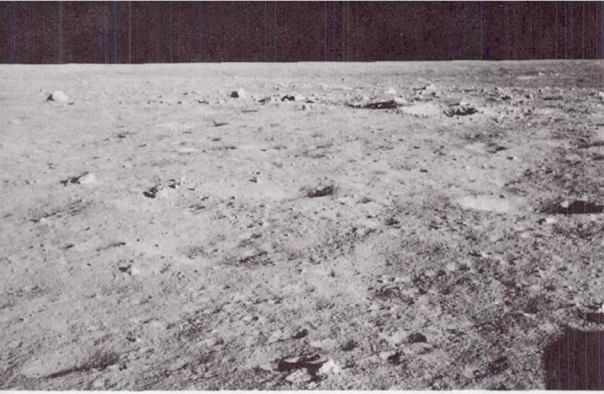
All during the exercise, the consumables were adequate, and flight control extended the time on the surface by 15 minutes. But, still too soon, CapCom McCandless finally had to tell Aldrin he would have to head back for the cabin in 10 minutes. The lunar module had withstood the landing well. It had apparently been a very soft landing, because the footpads had sunk only about five centimeters into the soil. The pilots found little wrong with their machine except some broken thermal insulation (the gold foil) on the lander's legs.

After an hour and three-quarters on the surface, Aldrin heard McCandless say, "Head on up the ladder, Buzz." The first step was a long one, and the soil on the soles of his boots made the rungs slippery, but he made it. Using the pulley, the crew hauled the sample boxes and cameras back into the cabin. Armstrong did a deep knee bend and jumped straight up, almost two meters, to the third rung of the ladder. Neither crewman had any trouble getting into the cabin. Once inside, they threw out a number of items that were just taking up space. For the most part, the crew was out of touch with the earth at this time, because the backpack antennas were again scratching against the ceiling. Flight control told Collins that the lunar walkers had returned to their ship, and he shouted, "Hallelujah."

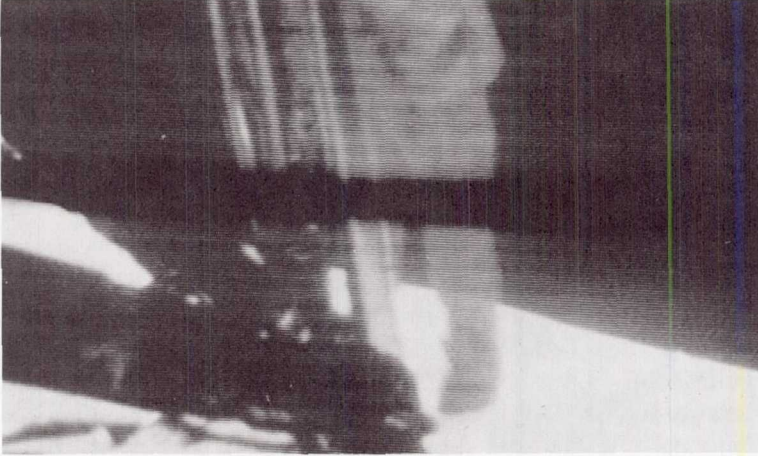
Armstrong and Aldrin found the post-EVA check easier than the preparations for getting out, but there was a long checklist to work through. They were glad they had tossed out some of the equipment, because there was still a "truckload" in the cabin. They ate during this period, but made no real attempt to relax, let alone sleep. They knew they could not sleep if all the launch preparations were not finished. They wondered how Collins was faring, racing around upstairs getting ready for the rendezvous.

Once they had finished their chores and were ready to call it a night, flight control began a question-and-answer session on the lunar surface operations. This came after they had already said "good night" twice. When the questions began to require extensive answers, especially on geology, Aldrin asked Houston to postpone the discussion until later. Flight control agreed, and Owen Garriott (now at the capcom console) said he hoped this transmission would be the final good night.

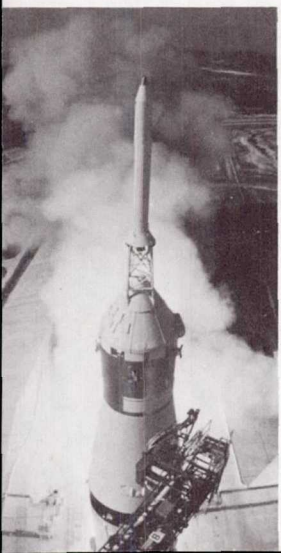
Armstrong and Aldrin found their lunar house dirty, noisy, crowded, and too brightly lit. They put on their helmets to keep from breathing the dust, to muffle the racket, and to protect themselves in any unexpected cabin depressurization. Shutting out the light was not so easy. The shades over the windows were little more than transparent sheets; even the lunar horizon could be seen through them. When Armstrong noticed that the light seemed to be getting stronger, he opened his eyes to find that the earth was pouring its rays through the sextant.



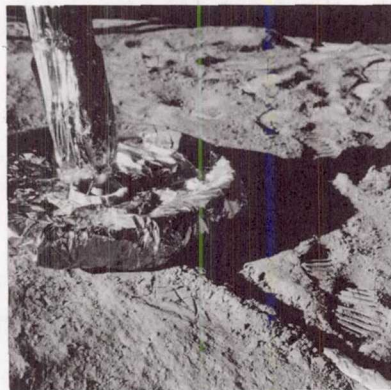
Apollo 11: the view out the window (left) after touchdown—no footprints on the moon. The lunar module's shadow is in the lower right corner. Below, Armstrong takes mankind's first step toward the lunar surface, while millions on earth watch via television.



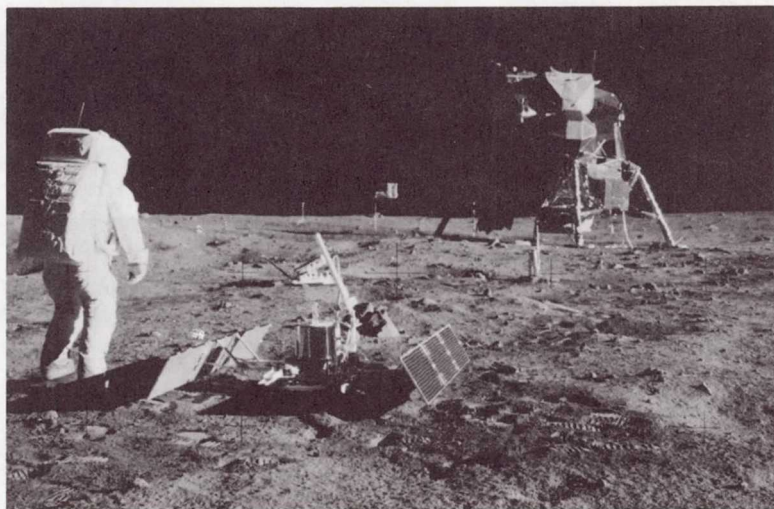
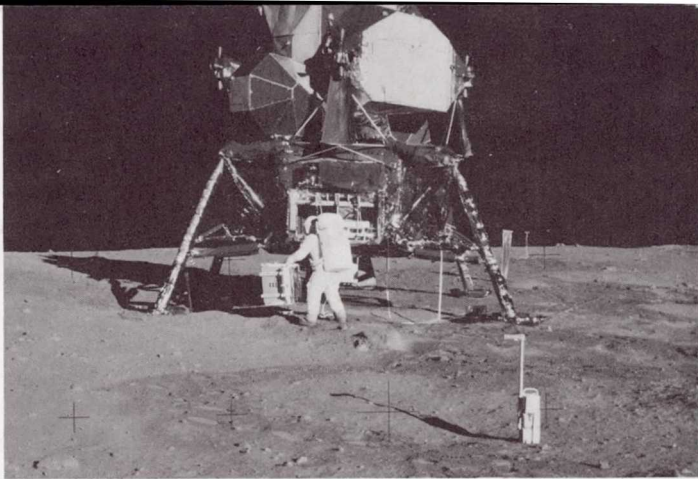
Aldrin descends the ladder (left). After years of questions as to whether the lunar soil would bear the weight of a vehicle without its sinking deep into dust, the footpads of Eagle (below) made only a slight impression.



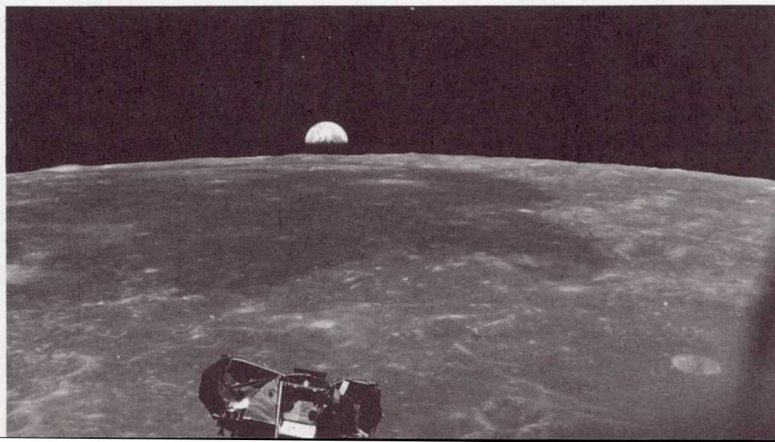
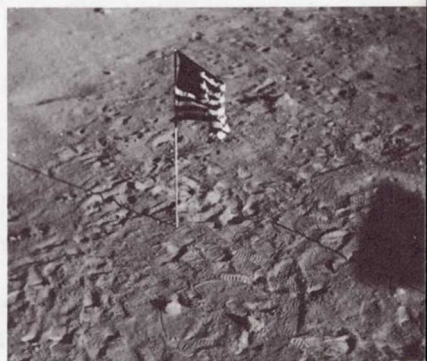
Apollo 11 lifts off for the moon.



Armstrong photographed Aldrin as he deployed scientific experiments at Tranquility Base. In the foreground at right is the 35 mm stereo closeup camera. Below, Aldrin stands by the passive seismic instrument, with the laser device in front of him. Beyond the U.S. flag is the black and white television camera.



The view from the window (right)—footprints and the flag, left behind on the moon. As Eagle (below) rose to dock with CM Columbia, “home Earth,” the next target to land on, came into view on the lunar horizon.



CHARIOTS FOR APOLLO

Getting to sleep proved to be a constant battle, and neither pilot was sure that he ever completely dozed off. Aldrin was on the floor, and Armstrong was on the ascent engine cover with his legs in a sling he had rigged up from a tether. Neither was uncomfortable at first—the suits were no problem (“You have your own little snug sleeping bag,” Aldrin said)—but soon they began feeling cold. After a time, and much fiddling with the controls, they were warmer, but they told Houston that future moon pilots should adjust the cabin temperature before they started to rest.

While his crewmates had been active on the surface, Collins had been busy in the command module. There was not much navigating to do, so he took pictures and looked out the window, trying to find the lunar module. He never found it; neither did flight control. There was just too much real estate down there to be able to search the whole area properly. Collins divided the part of the moon he was flying over into segments, but he had no better luck. Armstrong and Aldrin had taken the 26-power monocular with them, but Collins did not think it would have helped much, anyway. He did complain that all this searching cut into the time he needed for taking pictures on each circuit, but he was philosophical about it. As he said, “When the LM is on the surface, the command module should act like a good child and be seen and not heard.”¹⁰

RETURN FROM TRANQUILITY

After their fitful rest period, the moon dwellers were roused by Houston and told to get ready to leave. Flight control and the crew discussed the most probable location of the lunar module, and Armstrong and Aldrin then aligned the guidance platform by the moon’s gravity field. They had some difficulty finding enough stars to sight on, but the *Eagle* was ready to take off on 21 July—21 hours 36 minutes after landing and more than 124 hours after leaving the earth on 16 July. Up above, Collins had been alone since the 13th revolution, and he did not expect to have company until the 27th circuit, 28 hours after the lander had separated from the command module. As the time drew nearer for ignition of the ascent engine, Collins positioned his ship so its radar transponder would be pointing in the direction of the lunar module radar signal. Everything was ready for the next critical move.

The *Eagle* lifted off the moon exactly on time, soaring straight up for 10 seconds to clear its launch platform (the descent stage) and the surrounding ground obstacles. When its speed reached 12 meters per second, it pitched over into a 50-degree climbing angle. Armstrong and Aldrin heard the pyrotechnics fire and saw “a fair amount of debris” when they first detected motion. The onset of this velocity was absolutely smooth, and they had difficulty sensing the acceleration. But when the cabin tilted over and

TRIP TO TRANQUILITY

they could see the lunar surface, they realized that they were going fast. On several occasions, familiar landmarks indicated they were on a correct flight path—Armstrong spoke of one named “Cat’s Paw” and Aldrin spotted “Ritter” and “Schmidt.”

Stafford and Cernan had told Armstrong about their lander’s lazy, wallowing “Dutch roll,” and the *Eagle* was flying the same way. When the engine had fired for seven minutes, the lunar module had reached an elliptical orbit of 17 by 84 kilometers, and the race to catch the mother ship was on. Another hurdle had been successfully vaulted. Collins could now call on one of the 18 recipes in his rendezvous cookbook to rescue the lander if necessary. An hour after the ascent engine’s first firing, Armstrong turned it on again, to kick the low point of the path up to 85 kilometers, to a nearly circular orbit. After checking the results with flight control, as well as with Armstrong and Aldrin, Collins found that the lander was on a good flight path. He could let orbital mechanics take over and wait until Armstrong slowed the lander’s catchup speed at the proper moment.

Eventually, Collins told his crewmates to turn off their tracking light; he could see them fine without it. Later, as the lander turned the lunar corner and lost contact with the earth, Armstrong slowed his vehicle for stationkeeping 30 meters from the command module, so Collins could inspect the lander before docking. During the inspection, Collins asked his shipmates to roll over a bit more, and they went straight into gimbal lock. Armstrong blamed himself for “the goof,” but it posed no real problems. Like all the lunar modules, the *Eagle* was a sporty machine once it was rid of its descent stage and much of its ascent engine fuel, and it took skill to keep the skittish bird from dancing about. Four hours after lunar launch, the two vehicles were ready to dock.

Collins rammed the probe dead center into the lander’s drogue. With the ascent stage fuel tanks nearly empty, he met with little resistance; it felt almost as though he was shoving the command module into a sheet of paper. He had to look out the window to make sure they were docked. Then he pressed the switch to reel the lander in closer and secure it with the capture latches. Suddenly there was a big gyration in yaw—perhaps because of the retraction, perhaps because of a lunar module thruster that seemed to be firing directly at the command ship. Collins used his handcontroller to steady the vehicles. Just as he was wondering if he would have to cut loose and try again, *Columbia* grabbed the *Eagle* and held on.

Collins hurried to get the hatch and probe out of the way, to greet his returning companions. As he did, the same strong smell of burnt electrical insulation met his nostrils. But, again, nothing seemed to be wrong. Armstrong and Aldrin began vacuuming the lunar dust from themselves, their equipment, and the sample boxes. The dust did not bother the trio much, and they began unloading, cleaning, and stowing. Their progress was so good that flight control considered bringing them home one revolution earlier

CHARIOTS FOR APOLLO

than the planned 31st circuit (one less than the Stafford crew had traveled). But they decided against it.

During the 28th orbit, Armstrong reported the crew safely aboard the command ship. Flight control soon signaled the lander to remain near the moon until its orbit decayed and it crashed on the surface. The *Eagle* flew slowly away, its thrusters firing to maintain attitude. Aldrin thought he saw some cracks in its skin, but Houston told him that cabin pressure was steady. That had been one very good bird.

Now the crew had nothing to do but rest, eat, take pictures, and wait to begin the return to earth. Collins did wrestle with some command module attitude excursions but, once the big service module engine fired behind the moon, the ship steadied, right on course. The firing lasted so long that Collins wondered if the automatic turnoff was going to work. Just as he reached for the switch, the engine stopped. After the crew had checked the results, all they could do was ride their stable machine home. Armstrong asked when they would acquire the flight control signal, and Aldrin, now totally relaxed, answered that he did not have "the foggiest" notion. Soon the commander wanted to know if anyone had any choice greetings when they did talk to Houston, but no one volunteered. Aldrin readied a camera to photograph the earthrise. Coming around the corner, Collins called to CapCom Duke, "Time to open up the LRL doors, Charlie."

Now they "mostly just waited," as Collins later said. Flight control passed up the usual newscast, telling them that only four nations* in the world had not told their citizens about the flight. President Nixon, in his White-House-to-Moon chat, had mentioned that he would meet them on the *Hornet*; now they learned that he was sending them on a world tour. After more news—about Vietnam, the Middle East, oil depletion allowances, and a drop in the Dow industrial averages—the astronauts knew they had truly returned from Tranquility.

On television they, like the Borman and Stafford crews before them, philosophized about the significance of their voyage. Armstrong spoke of the Jules Verne novel about a trip to the moon a hundred years earlier, underscoring man's determination to venture out into the unknown and to discover its secrets. Collins talked of the technical intricacies of the mission hardware, praising the people who had made it all work. Aldrin spoke about what the flight meant to mankind in striving to explore his universe and in seeking to promote peace on his own planet. Armstrong closed the session, speaking of Apollo's growth from an idea into reality and ending with, "God bless you. Good night from Apollo 11."

The pilots watched the earth grow larger and larger. They televised more of life in a spacecraft. A day before landing, they checked out the

* China, Albania, North Korea, and North Vietnam.

TRIP TO TRANQUILITY

command module entry monitoring system, so flight control could check for "any funnies," as Collins called them. But there did not appear to be any. Stowage went smoothly. After they turned the ship into the reentry position and kicked off the service module, they saw it sail by, carrying with it the engine that had served them so well.

As they neared the earth, Houston began grumbling about the weather in the target zone—thunderstorms and poor visibility. Finally the landing point was moved. Collins was not very happy about trying to reach a spot 580 kilometers farther downrange than he had trained for. He did not complain, but he worried some.

When the command module hit the reentry zone, Aldrin triggered a camera to capture on film, as best he could, the colors around the plasma sheath—lavenders, little touches of violet, and great variations of blues and greens wrapped around an orange-yellow core. A surprisingly small amount of material seemed to be flaking off the spacecraft; Collins did not see the chunks he had seen in Gemini.

By now, the crew had turned the spacecraft over to its computer—that fourth crew member who had done a lot of the mission flying to this point—and were watching the entry monitor. The computer held on to a small downrange error for a while, decided it was wrong, and dumped the figure. The vehicle dipped down into the atmospheric layer, zipped up in a roller coaster curve out of the layer, and then came screaming back in. The drogue parachutes opened, and the ship steadied. Armstrong and his crew felt the jerk as the main parachutes came out; it seemed to take a long time for those three parachutes to blossom. Some good sounds came up from below as they heard the recovery forces trying to talk to them at the end of the reentry communications blackout. Reentry was fairly comfortable for the crewmen, without their bulky suits, but splashdown came with a jolt—24 June 1969—8 days, 3 hours, 18 minutes, 18 seconds after leaving Cape Kennedy.*

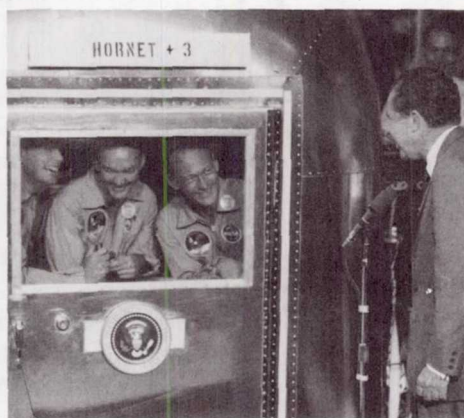
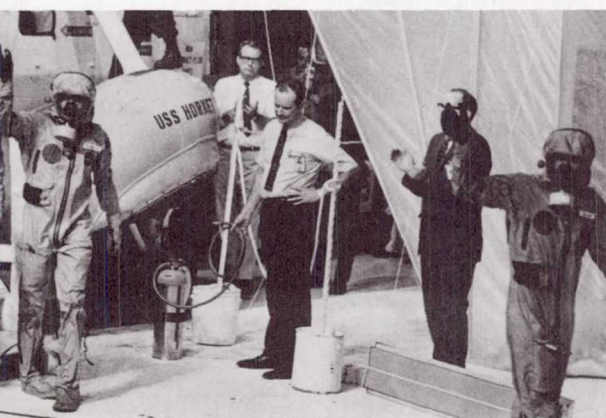
Columbia landed close to its reprogrammed target and flipped over on its nose in the water, but a flick of a switch inflated the air bags and it soon turned upright. None of the crew were seasick, but they had taken preventive medication before the landing. They went through a lengthy checklist of the things to be done to keep the world free from contamination. It had been a long trip.

A swimmer threw them the biological isolation garments, and they put them on. Armstrong disembarked first, followed by Collins and then Aldrin. As they passed through the hatch they inflated their water-wing life preservers before jumping into the raft. Armstrong noticed that a swimmer was

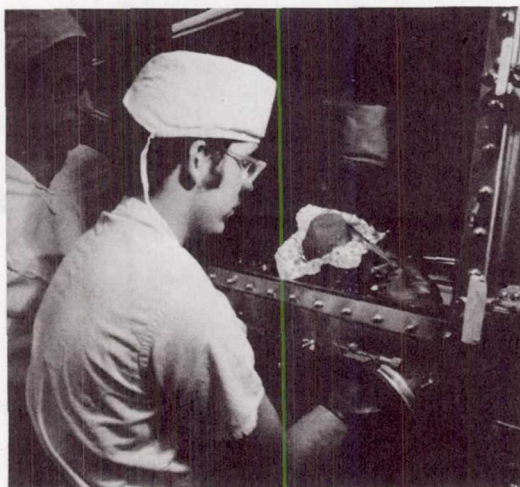
* According to the command module computer, *Columbia* landed at 13°19' north latitude and 169°9' west longitude.



Mission Control celebrates the successful conclusion of the Apollo 11 mission that landed men on the moon and returned them safely to the earth.



Looking like three men from another planet in their biological isolation garments, Aldrin, Armstrong, and Collins (left to right at left above) step from the helicopter onto the deck of the carrier Hornet on their way into the Mobile Quarantine Facility. After removing the isolation garments and freshening up, the three (Armstrong, Collins, and Aldrin, left to right at right above) are greeted by President Nixon.



Scientists in the Lunar Receiving Laboratory, working through glove ports, examine a moon rock.

TRIP TO TRANQUILITY

having trouble closing the hatch; he went over to help—the commander did not want anything to happen to “those million dollar rocks.” He had trouble, too, so Collins came back and adjusted the handle; then they closed the door.

In the rubber boat, the astronauts were scrubbed down with an iodine solution by the swimmers; they, in turn, did the same for the frogmen. While a helicopter lifted the crew to the U.S.S. *Hornet*, the spacecraft got its scrubdown before it, too, was lifted to the ship. The travelers stepped from the aircraft onto the carrier deck and straight into the mobile isolation unit. The “national objective of landing men on the moon and returning them safely to earth before the end of the decade” had been achieved.

But the safe recovery was not the end of activities for *Apollo 11*. First, the crewmen changed from the isolation garments to more comfortable flight suits and crowded to the door where, behind glass, they presented their now familiar countenances (although Collins had grown a moustache that altered his looks) to the TV cameras. Years of study of the lunar samples lay ahead, and the crew had to spend their 21 days in quarantine. During that period, they answered a formidable set of questions about everything that had taken place, relying on both notes and memory, to make sure that they had done all they could to assist the crews that would follow them to the moon. Collins closed these thorough and exhaustive sessions by saying, emphatically, “I want out.”

When they did get out, there was the swirl of a world tour; men and women from all walks of life, of varying colors, creeds, and political persuasions, both young and old, hailed the feat of mankind’s representatives.

“For one priceless moment . . .”¹¹

One of the stops before Collins (at the speakers stand), Armstrong, and Aldrin left on a world tour was to report to a joint session of Congress.



CHARIOTS FOR APOLLO

Apollo 11 Mission Events Sequence

<i>Event</i>	<i>Time hr:min:sec</i>
Range zero—13:32:00 GMT, 16 July 1969	
Liftoff	00:00:00.6
S-IC outboard engine cutoff	00:02:41.7
S-II engine ignition (command)	00:02:43.0
Launch escape tower jettison	00:03:17.9
S-II engine cutoff	00:09:08.3
S-IVB engine ignition (command)	00:09:12.2
S-IVB engine cutoff	00:11:39.3
Translunar injection maneuver	02:44:16.2
CSM/S-IVB separation	03:17:04.6
First docking	03:24:03.1
Spacecraft ejection	04:16:59.1
Separation maneuver (from S-IVB)	04:40:01.8
First midcourse correction	26:44:58.7
Lunar orbit insertion	75:49:50.4
Lunar orbit circularization	80:11:36.8
Undocking	100:12:00.0
Separation maneuver (from LM)	100:39:52.9
Descent orbit insertion	101:36:14.0
Powered descent initiation	102:33:05.2
Lunar landing	102:45:39.9
Egress (hatch opening)	109:07:33.0
Ingress (hatch closing)	111:39:13.0
Lunar liftoff	124:22:00.8
Coelliptic sequence initiation	125:19:36.0
Constant differential height maneuver	126:17:49.6
Terminal phase initiation	127:03:51.8
Docking	128:03:00.0
Ascent stage jettison	130:09:31.2
Separation maneuver (from ascent stage)	130:30:01.0
Transearth injection maneuver	135:23:42.3
Second midcourse correction	150:29:57.4
CM/SM separation	194:49:12.7
Entry interface	195:03:05.7
Landing	195:18:35.0

TRIP TO TRANQUILITY

Apollo 11 Recovery Sequence

<i>Event</i>	<i>Time, GMT</i>
	<i>24 July</i>
Visual contact by aircraft	16:39
Radar contact by U.S.S. <i>Hornet</i>	16:40
VHF voice and recovery-beacon contact	16:46
CM landing	16:50
Flotation collar inflated	17:04
CM hatch open	17:21
Crew egress in biological isolation garments	17:29
Crew aboard <i>Hornet</i>	17:53
Crew in Mobile Quarantine Facility (MQF)	17:58
CM lifted from water	19:50
CM secured to MQF	19:58
CM hatch reopened	20:05
Sample return containers 1 and 2 removed from CM	22:00
Container 1 removed from MQF	23:32
	<i>25 July</i>
Container 2 removed from MQF	00:05
Container 2 and film sent to Johnston Island	05:15
Container 1, film, and biological samples sent to Hickam AFB, Hawaii	11:45
Container 2 and film arrival in Houston	16:15
Container 1, film, and biological samples arrival in Houston	23:13
	<i>26 July</i>
CM decontaminated and hatch secured	03:00
MQF secured	04:35
	<i>27 July</i>
MQF and CM offloaded	00:15
Safing of CM pyrotechnics completed	02:05
	<i>28 July</i>
MQF arrival at Houston	06:00
Flight crew to LRL	10:00
	<i>30 July</i>
CM delivery to LRL	23:17

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Epilogue

After eight years—May 1961 to July 1969—the Apollo program, overcoming obstacles and tragedy, accomplished the goal set by the nation. Americans had walked on the moon and returned to talk about it. Pre-eminence in space flight, an oftstated objective, had been achieved in such style that the two-nation space race was seldom mentioned again, except by those who doubted that the Russians had ever intended to send men to the moon. What was achieved toward long-range progress and in contributions to science or national interest will be argued for years, perhaps decades. At the outset, however, little but public support for the program was heard. The direction of the manned space flight program followed the sentiments of Congress, the people, and members of the scientific community, who—tired of hearing about Soviet technological successes—reasoned that America needed to marshal its forces to catch up. Landing men on the moon seemed the best way to demonstrate this nation's prowess to the world. The possibility that there might, or might not, be any long-range gains was not really considered until this country faced new pressures that pushed reassessment of priorities. But even during the turmoil of domestic troubles and international problems, there were those who insisted that manned space flight, including walking on the moon, contributed materially to the well-being of mankind, citing especially the technological explosion that Apollo helped to trigger.

Although mutterings against the need for such a program grew during the later years, there was no change in the national objective to land men on the moon. Apollo received what it needed in money and support, even

CHARIOTS FOR APOLLO

during the time of tragedy and severest test. But the complexity and immensity of Apollo kept attention narrowly focused on the aim of getting men safely on and off the moon, leaving little time or talent available to plan the exploitation of the technology, enlist scientists to share in the manned space flight program, and frame some kind of program to follow Apollo.

By 1965, the spacecraft and the Saturn V still faced technical problems, but design and development had reached a point where manufacturing, production, and qualification could be expected to start soon, giving NASA its first opportunity to pause and look ahead. The agency's top administrators, who had seen Apollo through budgetary and congressional hearings, were dubious of suggestions that landing men on Mars should be the next step. Deputy Administrator Hugh Dryden said a few months before his death in December of that year, "I don't think you'll ever get another commitment out of the nation like [Apollo]. You just can't guarantee to make a national commitment that will extend over 8 or 10 years."¹ At that time, Apollo's price tag was \$3 billion a year; no matter how sound a long-range plan NASA might have presented, it is unlikely that the President, the Congress, and the American taxpayer, faced with the social and international pressures and turmoil of the middle years of the decade, would have supported a program to send men to the planets.

NASA might have wanted to aim for a planetary voyage, but the agency consensus was that it was best to amortize a significant percentage of Apollo's costs in near-earth orbital operations.² This decision led to a series of program planning steps—from the Apollo Extension System to Apollo Applications and finally to Skylab. For some time, this planning included exploring the moon after the first landing. In late 1967, however, NASA officials decided that all lunar landing missions should be part of the Apollo program. These flights were therefore transferred to a Lunar Exploration Office, established on 19 December at Headquarters and headed by Lee R. Scherer, former Lunar Orbiter Program manager at Langley.³

Scherer's group first tried to determine the content and objectives of these forthcoming lunar landings. It studied the use of a lunar flying unit, roving vehicles of various kinds, an extended lunar module (ELM) to land larger payloads on the moon, and an unmanned logistics system, perhaps launched by a Titan III-Centaur, that could supplement the ELM payload or form a lunar base shelter, among other things.

Director Robert Gilruth of the Manned Spacecraft Center favored upgrading Apollo's capabilities to support limited exploration and thought NASA should move more rapidly to this end. Gilruth wrote manned space flight head George Mueller at Headquarters of his concerns in March and again in April of 1968, pointing out that the President's Science Advisory Committee (PSAC) had gone on record that it would support no more than two or three lunar landings that met engineering goals only. PSAC wanted

Apollo to stay on the moon longer, to provide the crews with more range and mobility, and to carry a scientific payload big enough to justify the mission. These were large undertakings, and yet the impression had been created, Gilruth said, that NASA could wait a year before starting on these tasks. And that impression prevailed. Gilruth needed money to begin the work,⁴ but it was 1969 before any contracts to develop or modify hardware were awarded.

In October 1968, Gilruth set up a Lunar Exploration Working Group in Houston and appointed John Hodge to manage it. Hodge was well aware of the limited budget outlook and tried to plan lunar exploration missions that used only improved Apollo hardware, to avoid developing new major systems. Hodge focused the initial work of his group on extending the lander's capability.⁵

The pressures that brought changes in how much Apollo would carry to the moon also affected choices of the sites it would visit. Very early in the program—1961—Homer Newell had asked scientist Harold Urey to suggest sites of interest. Urey submitted a list of areas that extended over the face of the moon. But the lunar-orbit mode that was then becoming the accepted route confined the landings to within a few degrees of the lunar equator. In early 1968, at Apollo Director Samuel Phillips' request, John Eggleston and John Sevier, among others in Houston, began searching for feasible areas outside the so-called Apollo zone. Wilmot Hess asked Chris Kraft if his flight operations people could find some way to relax this equatorial zone restriction. Kraft answered that many of the constraints were crew safety provisions that could never be entirely eliminated, but some of the trajectories might be modified to save fuel. If propellant capacities on the vehicles could be increased, more sites on the face of the moon might be visited. Studies were soon in progress on two target areas frequently mentioned, lunar craters Copernicus and Tycho.⁶

Although the technologists realized by 1968 that scientific experiments could no longer be considered just "add-on pieces of equipment resulting in minimum modifications to space vehicles," so many unknowns remained for the first lunar landing that the size of the Apollo lunar surface experiments package (ALSEP) was reduced. But the engineers agreed that a full-scale ALSEP should be flown on a later mission. Moreover, they had begun to accept the idea that a successful first landing might warrant flying to a more scientifically interesting spot on the second mission—but one still within the ellipse of the Apollo zone. The procedure was called *biasing the flight*; in early 1969, the planners decided to bias a landing to the vicinity of a Surveyor spacecraft already resting on the lunar surface.⁷

By late 1968, there were indications that the lunar module would soon be accepted for flight. Hodge was then under pressure to get these vehicles modified to support the lunar exploration program. By February 1969, his group had written and rewritten a statement of work for the task. In late

CHARIOTS FOR APOLLO

April, Apollo Spacecraft Program Manager George Low buttonholed Phillips and asked when Houston could start on the engineering modifications for the exploration vehicles. Phillips authorized funds for the work through the first week in May, when he would take another look at the requirements. Mueller evidently liked the changes. On 26 May he advised NASA's new Administrator, Thomas Paine, that Houston had been instructed to modify the command module, starting with CM-112, to carry additional fuel and a scientific instrument module and to extend the staytime of LM-10 and subsequent spacecraft and to increase their payloads. Mueller expected the improved craft to be ready for flight by September 1970.⁸

After the *Apollo 9* flight in March 1969, when the lunar module did everything it would do in lunar flight except land on the moon, NASA added another letter to its lunar landing alphabet. Following the G mission (the first landing), all flights would be designated H. This meant that these missions would carry a complete ALSEP, stay on the lunar surface up to 35 instead of 22 hours, provide for two walks by the crews for a total of 6 hours rather than one walk for 3 hours, and permit a walking range of 900 instead of 100 meters away from the lunar module. A Bellcomm study that month showed that, with modifications to the trajectories and procedures, "the entire face of the moon" could be considered as the Apollo zone. With this encouragement, and the near certainty that *Apollo 11* would be successful, the Astro Geology Branch of the United States Geological Survey asked that the crews of the H missions visit both the "Eastern" (old) and "Western" (new) maria. The Apollo Site Selection Board heard a presentation on 10 July for a Western mare landing, and Mueller told Paine on 29 July that the next flight would aim for a landing in that area, in Oceanus Procellarum, only about 200 meters from *Surveyor III*'s landing point. In August, André Meyer was more than mildly upset that the mission planners were not giving enough priority to retrieving some *Surveyor* hardware.⁹

Mueller on 23 May 1969 had picked the lunar roving vehicle, to be housed in the descent stage of the lander, as the way to extend the range and capabilities of the exploration missions (later called J missions). All discussion of unmanned logistic landers for lunar shelters and bases ceased. Marshall Space Flight Center, directing the development of the rover, issued a request for proposals to industry on 11 July and followed that with a bidders' briefing at Michoud two weeks later. Low talked with Neil Armstrong and Edwin Aldrin after the *Apollo 11* flight and learned that Armstrong thought it would be just as easy getting around on foot as on the roving vehicle. Moreover, the crew said it was easy to carry tools to wherever they were needed and bring them and the samples back. Meyer disagreed with the astronauts, pointing out that they had not trained on the one-sixth-g trainer, which had shown that fatigue would limit the distance moon walkers could travel. Tests had indicated that the loping gait suggested by Armstrong would produce some very tired crews. Marshall evaluated the pro-

posals in August and awarded a contract to Boeing in October. Apollo had its "moon buggy," scheduled for missions to be flown in 1971 and 1972.¹⁰

Intervals between flights were discussed from time to time, with six months being mentioned most often. Mueller, who reportedly favored three to five lunar exploration flights a year, decided to fly one every ten weeks until the lunar landing. The investigators of the lunar sample experiments had petitioned NASA to launch the second landing mission no sooner than six months after the first. Mission planners and engineers, who had found flying five missions between October 1968 and July 1969 a grueling task, agreed with the scientists. If *Apollo 11* did not land on the moon, Mueller intended to follow it with flights in September and December, or until the national objective was reached. After the visit of Armstrong and Aldrin to Tranquility Base, Mueller relaxed the pressure. Charles Conrad, Alan Bean, and Richard Gordon did not fly *Apollo 12* until mid-November—not six months later, but at least double the intervals between the first five flights.¹¹

After *Apollo 11*, laboratories all over the country and in a number of others had stacks of data tapes and lunar samples to study, and the promise of more of each from the later flights, but this abundance did not alleviate the discontent of some members of the scientific community. Their main charge was that the scientists had no part in NASA's decision-making and no effective representation among NASA's top management since the death of Dryden in 1965. Urey complained to the President's Space Task Group, headed by Lee A. DuBridge, that he did not know who was making decisions on the landing sites nor why they were making these decisions. When he was informed of the selections, he said, so many unfamiliar acronyms were used that the text was undecipherable. When the scientists did take part in the selection process later, according to one NASA mission planner, the situation did not improve. Each scientist repeatedly voted for the site of his preference, frequently resulting in a stalemate. In the end, NASA had to step in and make the decision anyway.¹²

Urey was, however, just as critical of those who derisively called the lunar samples "a bag of rocks."

What a magnificent bag! Rocks last melted 3.65 billion years ago! Dust last chemically assembled 4.66 billion years ago back at the very beginning of the solar system and of our mother earth. We have those marvelous pictures of old mother earth as she floats in space.¹³

At the end of the sixties, then, Apollo had finished the job it was designed to do: land men on the moon and return them safely within that decade.

Although *Apollo 11* was the most remembered of all the flights and the primary source of arguments about whether America should have sent men to the moon at all, that mission was actually an engineering confirmation

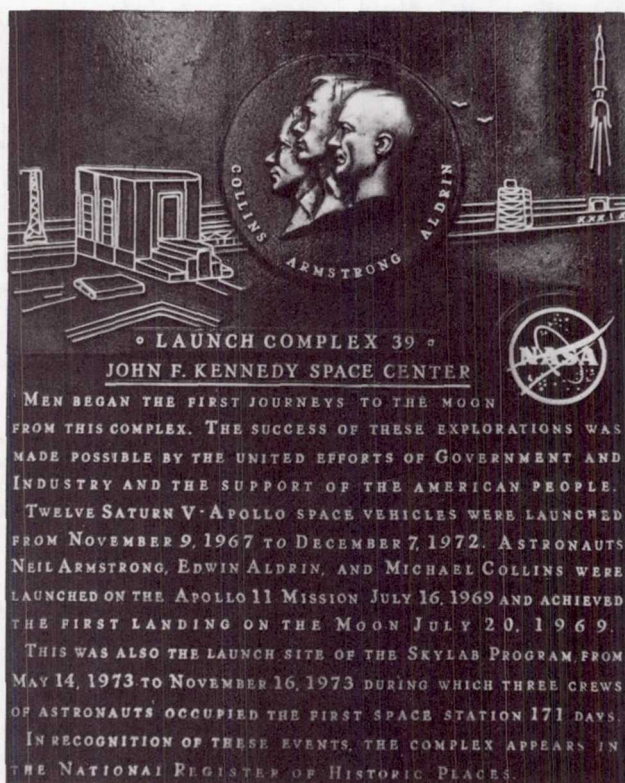
CHARIOTS FOR APOLLO

that astronauts could do the job. The missions that followed—*Apollo 12* through *Apollo 17*—were the limited exploitations of that capability. Study of the lunar data collected by the 12 men who walked on the moon, and by the experiments they left on the surface, would occupy scientists around the world for more than a decade beyond the final flight in 1972. Already the information had begun to give insights into how the moon, and hence the earth, had evolved. And immediately, as early as *Apollo 8*, flights to another celestial body brought a new awareness of the spaceship *Earth* and the need to preserve it.

In a still larger sense, *Apollo 11* demonstrated that with determination, time, and resources complex national goals could be achieved. “If we can put men on the moon, we can . . .”; or, “Why can’t we . . . ?”—although an oversimplification—became a benchmark for measuring progress, or a lack of it.¹⁴

Anthropologist Margaret Mead said on the eve of *Apollo 11* that it could be “a first step, not into space alone, but into the disciplined and courageous use of enhanced human powers for man, ennobled as he is today, as the first men step on the moon.” And afterward historian Arthur Schlesinger declared:

The 20th Century will be remembered, when all else is forgotten, as the century when man burst his terrestrial bonds.¹⁵



Five years later—16 July 1974—Launch Complex 39 was dedicated as a national landmark.

Appendixes

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Appendix A

Manned Spacecraft Center Site Selection Procedure

The procedure for selecting a site for a manned space flight laboratory, one of four major facilities required for the manned lunar landing mission set by the President, was as follows:

I. The selection of the site would be made by the NASA Administrator in conjunction with the Deputy Administrator.

II. As the first step in collecting information to assist the Administrator in the selection, on 7 July 1961 the Associate Administrator instructed the Director, Office of Space Flight Programs, to establish preliminary site criteria and to propose membership for a site survey team. The team, appointed on 7 August 1961, consisted of John F. Parsons, Chairman, Associate Director, Ames Research Center; N. Phillip Miller, Chief, Facilities Engineering Division, Goddard Space Flight Center; Wesley L. Hjornevik, Assistant Director for Administration, and I. Edward Campagna, Construction Engineer, Space Task Group. When Hjornevik was suddenly taken ill on 12 August 1961, he was replaced by Martin A. Byrnes, Project Management Assistant, Space Task Group.

III. The site survey team met on 11 August with the Director, Office of Space Flight Programs; the Associate Director, Space Task Group; and the Assistant Director for Manned Space Flight, Office of Space Flight Programs. During this meeting, tentative site requirements were developed.

Abstracted from James E. Webb, NASA Administrator, "Memorandum for the President," 14 September 1961, and attachment.

APPENDIX A

IV. The site requirements were formulated in detail by the site survey team. At a meeting with the Deputy Administrator, Director of Space Flight Programs, Director of the Office of Programs, and the Assistant Director for Facilities of the Office of Programs, the Administrator approved the following criteria:

Essential Criteria

1. *Transportation*: Capability to transport by barge large, cumbersome space vehicles (9 to 12 meters in diameter) to and from water shipping. Preferably the site should have its own or have access to suitable docking facilities. Time required in transport would be considered.

Availability of a first-class all-weather commercial jet service airport and a Department of Defense air base installation in the general area capable of handling high-performance military aircraft.

2. *Communications*: Reasonable proximity to main routes of the long-line telephone system.

3. *Local Industrial Support and Labor Supply*: An existing, well-established industrial complex, including machine and fabrication shops, to support a research and development activity of high scientific and technical content and to fabricate pilot models of large spacecraft.

A reliable supply of construction contractors and building trades craftsmen to permit rapid construction of facilities without premium labor costs.

4. *Community Facilities*: Close proximity to a culturally attractive community to permit the recruitment and retention of a staff with a high percentage of professional scientific personnel.

Close proximity to an institution of higher education, with emphasis on one specializing in the basic sciences and in space-related graduate and postgraduate education and research.

5. *Electrical Power*: Strong local utility system capable of developing up to 80 000 KVA of reliable power.

6. *Water*: Readily available, good-quality water system capable of supplying more than a million liters per day of potable water and the same amount of industrial water.

7. *Area*: 4 square kilometers with an available adjacent area for further development. Suitable areas in the general location for low hazard and nuisance subsidiary installations requiring some isolation.

8. *Climate*: Mild, permitting year-round, ice-free water transportation and out-of-door work for most of the year to facilitate operations, reduce facility costs, and speed construction.

Desirable Criteria

1. *Impact on Area*: Compatibility of proposed laboratory with existing regional planning and ability of community facilities to absorb the increased population and to provide the related industrial and transport support required.

2. *Site Development Costs*: Consideration of costs for site development required for proposed laboratory.

CENTER SITE SELECTION

3. *Operating Costs*: Consideration of costs for normal operations, including utility rates, construction costs, wage scales, etc.

4. *Interim Facilities*: Availability of reasonably adequate facilities for the temporary use of up to 1500 persons in the same general area as the permanent site.

V. The site survey team was instructed to survey possible sites using all available information and using the approved criteria to decide which should be visited by the team, visiting these sites and such others as might be directed by the Administrator, and preparing a report, including a listing of the advantages and disadvantages of each site considered.

VI. A team review of climatological data furnished by the United States Weather Bureau and information on water-borne commerce in the United States provided by the Corps of Engineers, Department of the Army, resulted in the following preliminary list of prospective areas that met the essential criteria of water transportation and climate:

Norfolk, Virginia; Charleston, South Carolina; Savannah, Georgia; Jacksonville, Miami, and Tampa, Florida; Mobile, Alabama; New Orleans and Baton Rouge, Louisiana; Memphis, Tennessee; Houston and Corpus Christi, Texas; San Diego, Los Angeles, Santa Barbara, and San Francisco, California; Portland, Oregon; and Seattle, Washington.

This list was then reviewed in light of the other essential site criteria and, through consultation with the General Services Administration, available surplus Government property. The list was reduced on 16 August 1961 to the following nine areas:

Jacksonville (Green Cove Springs Naval Station) and Tampa (MacDill Air Force Base), Florida; Baton Rouge and Shreveport (Barksdale Air Force Base), Louisiana; Houston (San Jacinto Ordnance Depot), Victoria (FAA Airport), and Corpus Christi (Naval Air Station), Texas; and San Diego (Camp Elliott) and San Francisco (Benecia Ordnance Depot), California.

To evaluate each area properly, a physical inspection by members of the team was essential. Accordingly, arrangements were made to visit these nine possible sites. In certain areas, additional possibilities were brought to the attention of the team and these localities were also visited. Hence, the 9 sites were increased to 23 by the inclusion of the following:

Bogalusa, Louisiana; Houston (University of Houston site, Rice University site, and Ellington Air Force Base), Liberty, Beaumont, and Harlingen, Texas; Berkeley, Richmond, and Moffett Field (Naval Air Station), California; and St. Louis (Daniel Boone site, Lewis and Clarke site, Industrial Park site, and Jefferson Barracks), Missouri.

Visits to the 23 sites began on 21 August and ended on 7 September 1961.

The team agreed that locations north of the freezing line were unlikely to meet the requirements and planned no visits in these areas. While the team was visiting the sites, however, several presentations were made directly to the Administrator, Deputy Administrator, and other NASA officials, notably by proponents of sites in the Boston, Rhode Island, and Norfolk areas. It was agreed that these cities would be considered in the final review.

APPENDIX A

On 12 August, the Administrator and Deputy Administrator reviewed the factors that had influenced the approved criterion on climate: "A mild climate permitting year-round, ice-free, water transportation; and permitting out-of-door work for most of the year to facilitate operations, reduce facility costs, and speed construction."

The considerations leading to this requirement were:

1. The reasons for specifying year-round, ice-free water transportation were self evident. It would be necessary to move the spacecraft and its components by water to other sites at any time of the year to avoid delays in the overall program.

2. The requirement for out-of-door work most of the year stemmed from experience with aircraft and large missiles. The spacecraft would be of comparable size, and an appreciable amount of fitting, checking, and calibration work would have to be done out of doors. Also the possibility of handling much larger spacecraft, such as a 10- to 15-man space station, had to be considered. The climate factor would become more important as larger spacecraft became part of the program.

3. A mild climate would avoid the necessity of special protection of the spacecraft against freezing of moisture in the many complicated components while transferring to and from sites and between site facilities. Providing such protection would be time-consuming and costly.

4. A mild climate would facilitate recovery-procedure training of the astronauts, as well as other activities that must be conducted out of doors.

5. A mild climate would permit a greater likelihood of day-to-day access by air to and from other parts of the country.

In summary, the selection of a site in an area that met the stated climate criterion would minimize both cost and time required for this project. A mild climate would also permit year-round construction, thereby accelerating the development of the project.

Appendix B

Astronaut Assignments

I. APOLLO ASTRONAUT ASSIGNMENTS AS ANNOUNCED IN 1966 AND 1967

Announced 21 March 1966

First manned flight—orbital

Prime crew: Virgil I. Grissom, Edward H. White II, and Roger B. Chaffee

Backup crew: James A. McDivitt, David R. Scott, and Russell L. Schweickart

Announced 29 September 1966

Second manned flight—orbital

Prime crew: Walter M. Schirra, Jr., Donn F. Eisele, and R. Walter Cunningham

Backup crew: Frank Borman, Thomas P. Stafford, and Michael Collins

APPENDIX B

Announced 22 December 1966

Second manned flight—dual mission with Saturn IBs

Prime crew: McDivitt, Scott, and Schweickart

Backup crew: Stafford, John W. Young, and Eugene A. Cernan

Third manned flight—first Saturn V flight

Prime crew: Borman, Collins, and William A. Anders

Backup crew: Charles Conrad, Jr., Richard F. Gordon, Jr., and Clifton C. Williams, Jr.

Announced 9 May 1967

First manned flight—Up-rated Saturn I

Prime crew: Schirra, Eisele, and Cunningham

Backup crew: Stafford, Young, and Cernan

Announced 20 November 1967

First manned flight—Up-rated Saturn I

Prime crew: Schirra, Eisele, and Cunningham

Backup crew: Stafford, Young, and Cernan

Support crew: John L. Swigert, Jr., Ronald E. Evans, and William R. Pogue

Second manned flight—Saturn V

Prime crew: McDivitt, Scott, and Schweickart

Backup crew: Conrad, Gordon, and Alan L. Bean

Support crew: Edgar D. Mitchell, Fred W. Haise, Jr., and Alfred M. Worden

Third manned flight—Saturn V

Prime crew: Borman, Collins, and Anders

Backup crew: Neil A. Armstrong, James A. Lovell, Jr., and Edwin E. Aldrin, Jr.

Support crew: Thomas K. Mattingly II, Gerald P. Carr, and John S. Bull

2. APOLLO ASTRONAUT ASSIGNMENTS AS FLOWN

Apollo 7—Saturn IB, orbital flight

Prime crew: Schirra, Eisele, and Cunningham

Backup crew: Stafford, Young, and Cernan

Support crew: Swigert, Evans, and Pogue

ASTRONAUT ASSIGNMENTS

Apollo 8—Saturn V, circumlunar flight

Prime crew: Borman, Lovell (Collins off the crew for surgery), and Anders

Backup crew: Armstrong, Haise (replacing Lovell), and Aldrin

Support crew: Mattingly, Carr, and Vance D. Brand (Bull had resigned from the program for reasons of health)

Apollo 9—Saturn V, orbital with LM

Prime crew: McDivitt, Scott, and Schweickart

Backup crew: Conrad, Gordon, and Bean

Support crew: Mitchell, Jack R. Lousma (replacing Haise), and Worden

Apollo 10—Saturn V, circumlunar flight with LM

Prime crew: Stafford, Young, and Cernan

Backup crew: L. Gordon Cooper, Jr., Eisele, and Mitchell

Support crew: Joe H. Engle, James B. Irwin, and Charles M. Duke, Jr.

Apollo 11—Saturn V, lunar landing

Prime crew: Armstrong, Collins, and Aldrin

Backup crew: Lovell, Anders, and Haise

Support crew: Mattingly, Evans, and Pogue

3. ASTRONAUT MISSION ASSIGNMENTS BY GROUP

Selected 9 April 1959

M. Scott Carpenter: Backup pilot on Mercury-Atlas 6 (MA-6); pilot on MA-7.

L. Gordon Cooper, Jr.: Backup pilot on MA-8; pilot on MA-9; command pilot on *Gemini V*; backup command pilot on *Gemini XII*; backup commander on *Apollo 10*.

John H. Glenn, Jr.: Backup pilot on Mercury-Redstone 3 (MR-3) and MR-4; pilot on MA-6.

Virgil I. Grissom: Pilot on MR-4; command pilot on *Gemini 3*; backup command pilot on *Gemini VI-A*; assigned as commander on *Apollo 1*, killed in fire on pad.

Walter M. Shirra, Jr.: Backup pilot on MA-7; pilot on MA-8; backup command pilot on *Gemini 3*; command pilot on *Gemini VI-A*; commander on *Apollo 7*.

Alan B. Shepard, Jr.: Pilot on MR-3; backup pilot on MA-9; commander on *Apollo 14*.

Donald K. Slayton: Assigned as pilot on MA-7 and then withdrawn because of heart fibrillation; docking module pilot on *Apollo-Soyuz*.

APPENDIX B

Selected 17 September 1962

- Neil A. Armstrong: Backup command pilot on *Gemini V*; command pilot on *Gemini VIII*; backup command pilot on *Gemini XI*; backup commander on *Apollo 8*; commander on *Apollo 11*.
- Frank Borman: Backup command pilot on *Gemini IV*; command pilot on *Gemini VII*; commander on *Apollo 8*.
- Charles Conrad, Jr.: Pilot on *Gemini V*; backup command pilot on *Gemini VIII*; command pilot on *Gemini XI*; backup commander on *Apollo 9*; commander on *Apollo 12*; commander on *Skylab 2*.
- James A. Lovell, Jr.: Backup pilot on *Gemini IV*; pilot on *Gemini VII*; backup command pilot on *Gemini IX-A*; backup command pilot on *Gemini X* (moved up to backup crew on *IX* after See and Bassett were killed in aircraft accident); command pilot on *Gemini XII*; backup command module pilot on *Apollo 8* (moved to prime crew when Collins underwent surgery), backup commander on *Apollo 11*; commander on *Apollo 13*.
- James A. McDivitt: Command pilot on *Gemini IV*; backup commander on *Apollo 1*; commander on *Apollo 9*.
- Elliot M. See, Jr.: Backup pilot on *Gemini V*; assigned as command pilot on *Gemini IX*, killed in aircraft accident.
- Thomas P. Stafford: Backup pilot on *Gemini 3*; pilot on *Gemini VI-A*; backup command pilot on *Gemini IX-A* (became prime crew command pilot after See was killed in aircraft accident); backup commander on *Apollo 7*; commander on *Apollo 10*; commander on *Apollo-Soyuz*.
- Edward H. White II: Pilot on *Gemini IV*; backup command pilot on *Gemini VII*; assigned as command module pilot on *Apollo 1*, killed in fire on pad.
- John W. Young: Pilot on *Gemini 3*; backup pilot on *Gemini VI-A*; command pilot on *Gemini X*; backup command module pilot on *Apollo 7*; command module pilot on *Apollo 10*; backup commander on *Apollo 13*; commander on *Apollo 16*; backup commander on *Apollo 17* (replacing Scott, when Irwin resigned).

Selected 18 October 1963

- Edwin E. Aldrin, Jr.: Backup pilot on *Gemini X* (moved to backup crew on *IX* after See and Bassett were killed in aircraft accident); pilot on *Gemini XII*; backup lunar module pilot on *Apollo 8* (moved to backup command module position when Lovell became member of prime crew); lunar module pilot on *Apollo 11*.
- William A. Anders: Backup pilot on *Gemini XI*; lunar module pilot on *Apollo 8*; backup command module pilot on *Apollo 11*.
- Charles A. Bassett II: Assigned as pilot on *Gemini IX*, killed in aircraft accident.
- Alan L. Bean: Backup command pilot on *Gemini X* when Lovell moved to backup crew on *IX* after the deaths of See and Bassett; backup com-

ASTRONAUT ASSIGNMENTS

- mand module pilot on *Apollo 9*; lunar module pilot on *Apollo 12*; commander on *Skylab 3*; backup commander on *Apollo-Soyuz*.
- Eugene A. Cernan: Backup pilot on *Gemini IX* (became prime pilot after Bassett was killed in aircraft accident); backup lunar module pilot on *Apollo 7*; lunar module pilot on *Apollo 10*; backup commander on *Apollo 14*; commander on *Apollo 17*.
- Roger B. Chaffee: Assigned to *Apollo 1*, killed in fire on pad.
- Michael Collins: Backup pilot on *Gemini VII*; pilot on *Gemini X*; command module pilot on *Apollo 8* (withdrew from the crew to undergo surgery); command module pilot on *Apollo 11*.
- R. Walter Cunningham: Lunar module pilot on *Apollo 7*.
- Donn F. Eisele: Command module pilot on *Apollo 7*; backup command module pilot on *Apollo 10*.
- Richard F. Gordon, Jr.: Backup pilot on *Gemini VIII*; pilot on *Gemini XI*; backup lunar module pilot on *Apollo 9*; command module pilot on *Apollo 12*; backup commander on *Apollo 15*.
- Russell L. Schweickart: Backup lunar module pilot on *Apollo 1*; lunar module pilot on *Apollo 9*; backup commander on *Skylab 2*.
- David R. Scott: Pilot on *Gemini VIII*; backup command module pilot on *Apollo 1*; command module pilot on *Apollo 9*; backup commander on *Apollo 12*; commander on *Apollo 15*; backup commander on *Apollo 17* (removed from flight status when Irwin resigned).
- Clifton C. Williams, Jr.: Backup pilot on *Gemini X*; killed in aircraft accident.

Selected 27 June 1965

- Owen K. Garriott: Science pilot on *Skylab 3*.
- Edward G. Gibson: Support crew on *Apollo 12*; science pilot on *Skylab 4*.
- Joseph P. Kerwin: Science pilot on *Skylab 2*.
- Harrison H. Schmitt: Backup lunar module pilot on *Apollo 15*; lunar module pilot on *Apollo 17*.

Selected 4 April 1966

- Vance D. Brand: Support crew on *Apollo 8* (replaced Bull, who had resigned for health reasons); support crew on *Apollo 13*; backup command module pilot on *Apollo 15*; backup commander on *Skylab 3* and *4*; command module pilot on *Apollo-Soyuz*.
- John S. Bull: Support crew on *Apollo 8* (resigned from the program for health reasons).
- Gerald P. Carr: Support crew on *Apollo 8* and *12*; commander on *Skylab 4*.
- Charles M. Duke, Jr.: Support crew on *Apollo 10*; backup lunar module pilot on *Apollo 13*; lunar module pilot on *Apollo 16*; backup lunar module pilot on *Apollo 17* (replacing Irwin, who resigned).

APPENDIX B

- Joe H. Engle: Support crew on *Apollo 10*; backup lunar module pilot on *Apollo 14*.
- Ronald E. Evans: Support crew on *Apollo 7* and *11*; backup command module pilot on *Apollo 14*; command module pilot on *Apollo 17*; backup docking module pilot on *Apollo-Soyuz*.
- Fred W. Haise, Jr.: Support crew on *Apollo 9* (moved to backup lunar module pilot on *8* when Lovell replaced Collins on prime crew); backup lunar module pilot on *Apollo 11*; lunar module pilot on *Apollo 13*; backup commander on *Apollo 16*.
- James B. Irwin: Support crew on *Apollo 10*; backup lunar module pilot on *Apollo 12*; lunar module pilot on *Apollo 15*; backup lunar module pilot on *Apollo 17* (resigned from program and replaced by Duke).
- Don L. Lind: Backup pilot on *Skylab 3* and *4*.
- Jack R. Lousma: Support crew on *Apollo 9* and *13*; pilot on *Skylab 3*.
- Thomas K. Mattingly II: Support crew on *Apollo 8* and *11*; command module pilot on *Apollo 13* (replaced by Swigert after being exposed to a communicable disease); command module pilot on *Apollo 16*.
- Bruce McCandless II: Support crew on *Apollo 14*; backup pilot on *Skylab 2*.
- Edgar D. Mitchell: Support crew on *Apollo 9*; backup lunar module pilot on *Apollo 10*; lunar module pilot on *Apollo 14*; backup lunar module pilot on *Apollo 16*.
- William R. Pogue: Support crew on *Apollo 7*, *13*, and *14*; pilot on *Skylab 4*.
- Stuart A. Roosa: Command module pilot on *Apollo 14*; backup command module pilot on *Apollo 16* and *17* (replaced Worden when Irwin resigned).
- John L. Swigert: Support crew on *Apollo 7*; backup command module pilot on *Apollo 13* (replaced Mattingly on prime crew when the latter was exposed to a communicable disease).
- Paul J. Weitz: Support crew on *Apollo 12*; pilot on *Skylab 2*.
- Alfred M. Worden: Support crew on *Apollo 9*; backup command module pilot on *Apollo 12*; command module pilot on *Apollo 15*; backup command module pilot on *Apollo 17* (removed from flight status when Irwin resigned).

Selected 4 August 1967

- Joseph P. Allen IV: Support crew on *Apollo 15*.
- Philip K. Chapman: Support crew on *Apollo 14* and *16*.
- Anthony W. England: Support crew on *Apollo 16*.
- Karl G. Henize: Support crew on *Apollo 16*.
- William B. Lenoir: Backup science pilot on *Skylab 3* and *4*.
- F. Story Musgrave: Backup science pilot on *Skylab 2*.
- Robert A. R. Parker: Support crew on *Apollo 15* and *17*.

ASTRONAUT ASSIGNMENTS

Transferred from USAF MOL program 13 August 1969

Charles G. Fullerton: Support crew on *Apollo 14* and *17*.
Henry W. Hartsfield, Jr.: Support crew on *Apollo 16*.
Robert F. Overmyer: Support crew on *Apollo 16*.
Donald H. Peterson: Support crew on *Apollo 16*.

4. CAPSULE COMMUNICATOR ASSIGNMENTS BY FLIGHT

MERCURY

MR-3: Control Center—Slayton.
MR-4: Control Center—Shepard.
MA-6: Control Center—Shepard; Bermuda—Grissom; California—Schirra;
Mucnea—Cooper.
MA-7: Control Center—Grissom; California—Shepard; Mucnea—Slayton;
Guaymas—Cooper.
MA-8: Control Center—Slayton; Hawaii—Grissom; California—Glenn;
Coastal Sentry Quebec—Shepard; Guaymas—Carpenter.
MA-9: Control Center—Schirra; Guaymas—Grissom; *Coastal Sentry* Que-
bec—Glenn; Hawaii—Carpenter.

GEMINI

Gemini 3: Cape—Cooper.
Houston—Chaffee (monitor).
Gemini IV: Cape—Williams.
Houston—Grissom.
Gemini V: Cape—Grissom.
Houston—McDivitt, Aldrin, Armstrong.
Gemini VII/
VI-A: Cape—Bean.
Houston—See, Cernan, Bassett.
Gemini VIII: Cape—Cunningham.
Houston—Lovell.
Gemini IX: Cape—Aldrin.
Houston—Armstrong, Lovell, Gordon, Aldrin.
Gemini X: Cape—Cooper.
Houston—Cooper, Aldrin.
Gemini XI: Cape—Williams.
Houston—Young, Bean.
Gemini XII: Cape—Roosa.
Houston—Conrad, Anders.

APPENDIX B

APOLLO

- Apollo 7:* Stafford, Evans, Pogue, Swigert, Young, Cernan.
Apollo 8: Collins, Mattingly, Carr, Armstrong, Aldrin, Brand, Haise.
Apollo 9: Roosa, Evans, Worden, Conrad, Gordon, Bean.
Apollo 10: Duke, Engle, Lousma, McCandless.
Apollo 11: Duke, Evans, McCandless, Lovell, Anders, Mattingly, Haise, Lind, Garriott, Schmitt.
Apollo 12: Carr, Gibson, Weitz, Lind, Scott, Worden, Irwin.
Apollo 13: Kerwin, Brand, Lousma, Young, Mattingly.
Apollo 14: Fullerton, McCandless, Haise, Evans.
Apollo 15: Allen, Fullerton, Henize, Mitchell, Parker, Schmitt, Shepard, Gordon, Brand.
Apollo 16: Peterson, Fullerton, Irwin, Haise, Roosa, Mitchell, Hartsfield, England, Overmyer.
Apollo 17: Fullerton, Overmyer, Parker, Allen, Shepard, Duke, Mattingly, Roosa, Young.

SKYLAB

- Skylab 2:* Truly, Crippen, Thornton, Hartsfield, Henize, Parker.
Skylab 3: Truly, Crippen, Thornton, Hartsfield, Henize, McCandless, Musgrave, Parker.
Skylab 4: Truly, Crippen, Hartsfield, McCandless, Musgrave, Thornton, Henize, Lenoir, Parker, Schweickart.

ASTP

Apollo-Soyuz: Bobko, Crippen, Truly, Overmyer (in Moscow).

Note: During Mercury, the astronauts manned the remote stations; in Gemini, flight control specialists had these assignments and the astronauts manned consoles at Launch Control at the Cape and at Mission Control in Houston. For Apollo, Houston assumed control when the launch vehicle cleared the tower. The launch flight director handled communications up to that point, then the astronaut capsule communicators in Houston took over. The last plan was also followed for Skylab and Apollo-Soyuz Test Project.

Appendix C

Apollo Flight Program

1. SATURN-APOLLO FLIGHTS (SATURN I)

Saturn-Apollo 1 (suborbital)

Launch: 27 October 1961, Complex 34, ETR, 01:00:06 p.m. EST.
Payload: Dummy second stage and Jupiter nose cone.
Delays: Two holds totaling 54 minutes for cloud cover over Cape.
Objectives: Flight-test eight clustered H-1 engines. Achieved.
Flight-test S-I stage clustered-propellant-tankage structure.
Achieved.
Flight-test S-I control system. Achieved.
Measure performance of bending and flutter, propellant sloshing, base heating, aerodynamic-engine torque, and air-frame aerodynamic heating. Achieved.

Saturn-Apollo 2 (suborbital)

Launch: 25 April 1962, Complex 34, ETR, 09:00:34 a.m. EST.
Payload: Dummy second stage and Jupiter nose cone.
Delays: Hold for 30 minutes for ship in downrange area.
Objectives: Prove first-stage propulsion system, structural design, and control system. Achieved.
Prove launch facilities and ground support equipment. Achieved.
Confirm vehicle aerodynamic characteristics in flight. Achieved.

APPENDIX C

Prove inflight performance of first-stage engines and adequacy to reach design velocity. Achieved.

Verify structural design of booster airframe. Achieved.

Demonstrate performance of guidance and control system. Achieved.

Release 86 685 liters of water in space (Project High Water 1) to upset concentration of water vapor in ionosphere and study conditions as equilibrium was regained. Achieved.

Saturn-Apollo 3 (suborbital)

Launch: 16 November 1962, Complex 34, ETR, 12:45:02 p.m. EST.
Payload: Dummy second stage and Jupiter nose cone.
Delays: Hold for 45 minutes for power failure in ground support equipment (GSE).
Objectives: Same as Saturn-Apollo 2. All achieved.

Saturn-Apollo 4 (suborbital)

Launch: 28 March 1963, Complex 34, ETR, 03:11:55 p.m. EST.
Payload: Dummy second stage and Jupiter nose cone.
Delays: Three technical holds, totaling 102 minutes.
Objectives: Same as Saturn-Apollo 2, with two exceptions:
1) Programmed premature cutoff of one engine to demonstrate that mission could be performed with one engine out.
2) No Project High Water.
All objectives achieved.

Saturn-Apollo 5 (orbital)

Launch: 29 January 1964, Complex 37B, ETR, 11:25:01 a.m. EST.
Payload: Live second stage, functional instrument unit, and Jupiter nose cone ballasted to simulate spacecraft mass characteristics.
Delays: Scrubbed on 27 January because of a test flange left in S-I stage liquid-oxygen (LOX) replenishment line, preventing flow of LOX to vehicle; 73-minute hold on 29 January because of interference in C-band radar and command-destruct frequencies.
Objectives: Flight-test launch vehicle propulsion, structure, and flight control systems. Achieved.
Flight-test live S-IV stage. Achieved.
Flight-test instrument unit. Achieved.
Demonstrate S-I/S-IV stage separation. Achieved.
Parameters: Apogee, 785 kilometers; perigee, 262 kilometers.

APOLLO FLIGHT PROGRAM

Saturn-Apollo 6 (A-101, orbital)

Launch: 28 May 1964, Complex 37B, ETR, 01:07:00 p.m. EDT.
Payload: Boilerplate 13 command and service module (CSM), production launch escape system (LES), and service module/launch vehicle adapter.
Delays: Scrubbed on 25 May because of faulty compressor in environmental control system of instrument unit; compressor replaced. Hold on 28 May for 38 minutes because platform could not be aligned in azimuth, improper performance of GSE; substitute panel used and alignment achieved. Hold for 60 minutes because of icing of the S-I stage LOX replenishment valve in GSE; valve purged. Hold for 75 minutes because surface winds caused LOX vapors to interrupt line of sight between ground theodolite and platform during azimuth alignment.
Objectives: Demonstrate launch vehicle propulsion, structure, and control. Achieved, except for engine no. 8 premature shutdown.
Flight-test closed-loop guidance. Achieved.
First flight test of Apollo spacecraft/launch vehicle configuration. Achieved.
Determine launch escape tower separation characteristics. Achieved.
Evaluate S-I/S-IV stage separation. Achieved.
Determine spacecraft launch and exit environmental parameters. Achieved.
Demonstrate LES jettison, using tower jettison motor. Achieved.
Parameters: Apogee, 227 kilometers; perigee, 182 kilometers.

Saturn-Apollo 7 (A-102, orbital)

Launch: 18 September 1964, Complex 37B, ETR, 11:22:43 a.m. EST.
Payload: Boilerplate 15.
Delays: Hold for 65 minutes caused by inadvertent activation of structure firex system, which sprayed water on vehicle and into S-IV stage umbilical connectors; connectors removed, dried out, replaced, and rechecked. Planned 21-minute hold extended to 25 minutes after a malfunction was indicated in the S-IV stage LOX-pressurizing-regulator circuits; indication false. Hold for 25 minutes because of apparent malfunction in S-I stage hydraulic pump temperature that prevented start of pump; malfunction found in GSE and bypassed. Hold for 49 minutes caused by intermittent operation of Grand Turk radar; radar repaired and count resumed.

APPENDIX C

- Objectives: Flight-test launch vehicle propulsion, structure, and control system. Achieved.
First closed-loop guidance flight for the full mission. Achieved.
Evaluate S-I/S-IV stage separation. Achieved.
Place 17 690 kilograms in orbit. Achieved.
- Parameters: Apogee, 225 kilometers; perigee, 185 kilometers.

Saturn-Apollo 8 (A-104, orbital)

- Launch: 25 May 1965, Complex 37B, ETR, 3:35:01 a.m. EDT.
Payload: Boilerplate 26 and *Pegasus II*.
Delays: None.
Objectives: Provide data on near-earth micrometeoroid environment by measurement of frequency of sensor penetrations. Achieved.
Parameters: *Pegasus II*: apogee, 742.6 kilometers; perigee, 505.3 kilometers; boilerplate jettisoned on insertion.

Saturn-Apollo 9 (A-103, orbital)

- Launch: 16 February 1965, Complex 37B, ETR, 09:37:03 a.m. EST.
Payload: Boilerplate 16 and *Pegasus I*.
Delays: Hold for 30 minutes to discharge Pegasus battery, recharge, and certify proper operation (replaced usual, 30-minute hold at T-30); 67-minute hold for power failure in range flight safety computer.
Objectives: Same as for *Pegasus II*. Achieved.
Parameters: *Pegasus I*: apogee, 743.4 kilometers; perigee, 495.4 kilometers.

Saturn-Apollo 10 (A-105, orbital)

- Launch: 30 July 1965, Complex 37B, ETR, 09:00:00 a.m. EDT.
Payload: Boilerplate 9 and *Pegasus III*.
Delays: None.
Objectives: Same as for *Pegasus I* and *II*. Achieved.
Parameters: *Pegasus III*: apogee, 532 kilometers; perigee, 532 kilometers.

2. PAD ABORT TESTS

Pad Abort 1

- Launch: 7 November 1963, WSMR, 09:00:01 a.m. MST.
Vehicle: Boilerplate 6, with tower structure, launch-escape motor, pitch-control motor, tower-jettison motor, and tower-release mechanism.

APOLLO FLIGHT PROGRAM

Delays: None.
Objectives: Determine aerodynamic stability characteristics of escape configuration during pad abort. Achieved.
Demonstrate capability of escape system to propel command module to safe distance from launch vehicle during pad abort. Achieved.
Demonstrate launch-escape timing sequence. Achieved.
Demonstrate proper operation of tower-release device. Achieved.
Demonstrate proper operation of tower-jettison and pitch-control motors. Achieved.
Demonstrate earth-landing timing sequence and operation of parachute subsystem. Achieved.
Parameters: Maximum altitude, 1600 meters; landing point, 1380 meters downrange.

Pad Abort 2

Launch: 29 June 1965, WSMR, 06:00:01 a.m. MST.
Vehicle: Boilerplate 23A, with launch escape system equipped with canard subsystem and boost protective cover.
Delays: None.
Objectives: Demonstrate capability of LES to abort from launch pad and recover. Achieved.
Parameters: Maximum altitude, 1578 meters; landing point, 2316 meters downrange.

3. LITTLE JOE II TESTS

A-001

Launch: 13 May 1964, WSMR, 05:59:59 a.m. MST.
Payload: Boilerplate 12, with escape system.
Delays: Scrubbed on 12 May for unacceptable wind conditions.
Objectives: Demonstrate structural integrity of escape tower. Achieved.
Demonstrate capability of escape system to propel command module to predetermined distance from launch vehicle. Achieved.
Determine aerodynamic stability characteristics of escape configuration for abort conditions. Achieved.
Demonstrate proper separation of command module from service module. Achieved.
Demonstrate satisfactory recovery timing sequence in earth-landing subsystem. Achieved.

APPENDIX C

Parameters: Maximum altitude, 4700 meters; landing point, 3530 meters downrange.

A-002

Launch: 8 December 1964, WSMR, 08:00:00 a.m. MST.
Payload: Boilerplate 23, with escape system equipped with canards.
Delays: None.
Objectives: Demonstrate satisfactory launch-escape power-on stability for abort in maximum dynamic pressure region (max q) with conditions approximating emergency detection subsystem limits. Achieved.
Parameters: Maximum altitude, 4683 meters; landing point, 2316 meters downrange.

A-003

Launch: 19 May 1965, WSMR, 06:01:04 a.m. MST.
Payload: Boilerplate 22 and launch escape system.
Delays: None.
Objectives: Demonstrate satisfactory launch escape vehicle (LEV) performance at altitude approximating upper limit for canard subsystem. Not achieved. Little Joe II booster experienced very high roll rate and disintegrated at low altitude.
Demonstrate orientation of LEV to main heatshield forward attitude after high-altitude abort. Not achieved.
Parameters: Maximum altitude, 5944 meters; landing point, 5486 meters downrange.

A-004

Launch: 20 January 1966, WSMR, 08:17:01 a.m. MST.
Payload: Production model CSM-002.
Delays: Scrubbed on 18 January for low ceiling and poor visibility.
Hold for 17 minutes on 20 January for loss of two WSMR telemetry stations; repaired before flight.
Objectives: Demonstrate satisfactory LEV performance of abort in power-on tumbling boundary region. Achieved.
Demonstrate structural integrity of LEV air-frame structure for such an abort. Achieved.
Parameters: Maximum altitude, 22 600 meters; landing point, 34 630 meters downrange.

APOLLO FLIGHT PROGRAM

4. UNMANNED APOLLO-SATURN FLIGHTS (SATURN IB AND SATURN V)

AS-201 (suborbital)

Launch: 26 February 1966, Complex 34, ETR, 11:12:01 a.m. EST.
Vehicle: Saturn IB.
Payload: CSM-009.
Delays: Hold for 3 days for bad weather conditions and for a break in subcable to downrange station. Hold for 30 minutes on 26 February to catch up on LOX loading. Hold for 30 minutes to complete liquid-hydrogen loading, which had been delayed by work on a GSE helium regulator problem. Hold for 78 minutes to complete closeout of spacecraft. Hold for 66 minutes because of cutoff caused by failure of helium pressure switch in Saturn IB ready circuit. Hold for 30 minutes (during which flight was canceled and then re-instated) for further information on helium pressure problem.

Objectives: Demonstrate structural integrity and compatibility of launch vehicle and spacecraft and confirm launch loads. Achieved. Demonstrate separation of first and second stages of Saturn, LES and boost protective cover from CSM, CSM from instrument unit/spacecraft/lunar module (LM) adapter, and CM from SM. Achieved. Verify operations of Saturn propulsion, guidance and control, and electrical subsystems. Achieved. Verify operation of spacecraft subsystems and adequacy of heatshield for reentry from low earth orbit. Partially achieved. Evaluate emergency detection system in open-loop configuration. Achieved. Evaluate heatshield ablator at high reentry rates. Not achieved because of loss of data during maximum heating. Demonstrate operation of mission support facilities. Achieved.

Parameters: Maximum altitude, 488 kilometers; landing point, 8472 kilometers downrange, 8.18°S, 11.15°W; miss distance, 72 kilometers; splashdown time, 11:49 a.m. EST.

Recovery: On board U.S.S. *Boxer* by 02:20 p.m. EST.

AS-202 (suborbital)

Launch: 25 August 1966, Complex 34, ETR, 1:15:32 p.m. EDT.
Vehicle: Saturn IB.
Payload: Spacecraft 011.

APPENDIX C

Delays: Hold for 60 minutes to resolve problem with launch vehicle digital computer during power transfer test; 48-minute hold for recurrence of computer problem; 41-minute hold to attempt to clear up problem with the remote site data processor on the *Rose Knot* Victor; 5-minute hold to evaluate Saturn IB low fuel mass quantity indicator.

Objectives: Same as AS-201. Achieved.

Parameters: Maximum altitude, 1143 kilometers; landing point, 16°7'N, 168°54'E; miss distance, 370 kilometers; splashdown time, 01:49 p.m. EDT.

Recovery: On board U.S.S. *Hornet* at 11:17 p.m. EDT.

AS-203. (orbital)

Launch: 5 July 1966, Complex 37B, ETR, 10:53:17 a.m. EDT.

Vehicle: Saturn IB.

Payload: Nose cone.

Delays: Hold for 4 minutes to examine quality of signal from liquid-hydrogen television cameras; 98-minute hold because of loss of signal from camera no. 2 (decision made to fly with one camera); 1-minute hold because of loss of Bermuda radar.

Objectives: Evaluate performance on S-IVB instrument unit stage under orbital conditions and obtain flight information on venting and chill-down systems, fluid dynamics and heat transfer of propellant tanks; attitude and thermal control system, launch vehicle guidance, and checkout in orbit. Achieved.

Parameters: Apogee, 189 kilometers; perigee, 185 kilometers.

Recovery: None.

Apollo 4 (AS-501, orbital)

Launch: 9 November 1967, Complex 39A, ETR, 07:00:01 a.m. EST.

Vehicle: Saturn V.

Payload: Spacecraft 017.

Delays: None.

Objectives: Demonstrate structural and thermal integrity and compatibility of launch vehicle and spacecraft; confirm launch loads and dynamic characteristics. Achieved.

Verify operation of command module heatshield (adequacy of Block II design for reentry at lunar return conditions), service propulsion system (SPS; including no ullage start), and selected subsystems. Achieved.

Evaluate performance of emergency detection system in open-loop configuration. Achieved.

APOLLO FLIGHT PROGRAM

- Demonstrate mission support facilities and operations needed for launch, mission conduct, and CM recovery. Achieved.
- Parameters: Apogee, 187 kilometers; perigee, 183 kilometers; during third orbit and after SPS engine burn, spacecraft coasted to simulated translunar trajectory, reaching an altitude of 18 079 kilometers; landing point, 30°06'N, 172°32'W; miss distance, 16 kilometers; splashdown time, 03:37 p.m. EST.
- Recovery: On board U.S.S. *Bennington* at 06:09 p.m. EST.

Apollo 5 (AS-204, orbital)

- Launch: 22 January 1968, Complex 37B, ETR, 05:48:08 p.m. EST.
- Vehicle: Saturn IB.
- Payload: LM-1 and nose cone.
- Delays: Hold for 228 minutes when spacecraft water boiler temperature rose higher than planned, caused by problem in GSE freon supply, and a power supply in an output register in the digital data-acquisition system failed.
- Objectives: Verify operation of LM ascent and descent propulsion systems. Achieved.
Evaluate LM staging. Achieved.
Evaluate S-IVB instrument unit performance. Achieved.
- Parameters: Apogee, 222 kilometers (at insertion, LM/S-IVB separation, and after first descent engine firing) and 961 kilometers (after first ascent engine firing); perigee, 163 kilometers (at insertion), 167 (at separation), 171 (after descent engine firing), and 172 kilometers (after ascent engine firing).
- Recovery: None.

Apollo 6 (AS-502, orbital)

- Launch: 4 April 1968, Complex 39A, ETR, 07:00:01 a.m. EST.
- Vehicle: Saturn V.
- Payload: CM-020, SM-014, LTA-2R.
- Delays: None.
- Objectives: Demonstrate structure and thermal integrity and compatibility of launch vehicle and spacecraft; confirm launch loads and dynamic characteristics. Achieved.
Demonstrate separation of launch vehicle stages. Achieved.
Evaluate performance of emergency detection system in closed-loop configuration. Achieved.
Verify operation of Saturn V propulsion, guidance and control, and electrical systems. Not achieved, because of early

APPENDIX C

cutoff of two of the S-II stage J-2 engines and failure of S-IVB J-2 engine to restart.

Demonstrate performance of mission support facilities. Achieved.

Parameters: Apogee, 367 kilometers; perigee, 178 kilometers (nearly circular orbit intended, but early cutoff of S-II engines and overburn of S-IVB engine caused unplanned orbital parameters); after S-IVB engine failed to reignite, a 442-second burn of the SPS engine sent the spacecraft to an altitude of 22 209 kilometers; exact landing point unknown, first visual sighting at 27°40'N, 157°59'W; splashdown time, 05:23 p.m. EST.

Recovery: On board U.S.S. *Okinawa* at 10:55 p.m. EST.

5. MANNED APOLLO-SATURN FLIGHTS (SATURN IB AND SATURN V)

Apollo 7 (AS-205, earth-orbital)

Launch: 11 October 1968, Complex 34, ETR, 11:02:45 a.m. EDT.

Vehicle: Saturn IB.

Payload: CSM-101.

Crew: Walter M. Schirra, Jr., Donn F. Eisele, and R. Walter Cunningham.

Delays: Hold for 2 minutes 45 seconds to complete S-IVB thrust chamber jacket chilldown.

Objectives: Demonstrate CSM/crew performance. Achieved.
Demonstrate crew/space vehicle/mission support facilities during manned CSM mission. Achieved.
Demonstrate CSM rendezvous capability. Achieved.

Parameters: Apogee, 285 kilometers; perigee, 227 kilometers; landing point, 27°32'N, 64°04'W; miss distance, 14 kilometers*; time, 07:12 a.m. EDT, 22 Oct.; mission elapsed time (MET), 260:08:58.

Recovery: Crew on board U.S.S. *Essex* at 08:20 a.m. EDT; spacecraft aboard ship at 09:03 a.m.

* Onboard computer target point was 27°37.8'N, 64°10.2'W; onboard computer landing point was 27°37.8'N, 64°10.8'W. Recovery ship landing point was 27°32.5'N, 64°04.0'W; indications are that the recovery ship may have been as much as ± 13 kilometers in error and that the spacecraft may actually have landed very close to the target point.

APOLLO FLIGHT PROGRAM

Apollo 8 (AS-503, lunar-orbital)

Launch: 21 December 1968, Complex 39A, ETR, 07:51:00 a.m. EST.
Vehicle: Saturn V.
Payload: CSM-103.
Crew: Frank Borman, James A. Lovell, Jr., and William A. Anders.
Delays: None.
Objectives: Demonstrate crew/space vehicle/mission support facilities during manned Saturn V/CSM mission. Achieved.
 Demonstrate translunar injection, CSM navigation, communications, and midcourse corrections. Achieved.
 Assess CSM consumables and passive thermal control. Achieved.
 Demonstrate CSM performance in cislunar and lunar orbit environment. Achieved.
 Demonstrate communications and tracking at lunar distances. Achieved.
 Return high-resolution photographs of proposed Apollo landing sites and locations of scientific interest. Achieved.
Parameters: Apogee, 190 kilometers; perigee, 180 kilometers; translunar injection, 02:56:05.5 MET; maximum distance from earth, 376 745 kilometers; lunar orbit insertion, 69:08:20 MET; lunar orbit, 312 by 111 kilometers; transearth injection, 89:19:17 MET; landing point, 8°7.5'N, 165°1.2'W; miss distance, 2.5 kilometers; splashdown time, 27 December at 10:52 a.m. EST; MET, 147:00:42.
Recovery: Crew on board U.S.S. *Yorktown* at 12:20 p.m. EST; spacecraft aboard ship at 01:20 p.m.

Apollo 9 (AS-504, earth-orbital)

Launch: 3 March 1969, Complex 39A, ETR, 11:00:00 a.m. EST.
Vehicle: Saturn V.
Payload: CSM-104, LM-3.
Crew: James A. McDivitt, David R. Scott, and Russell L. Schweickart.
Delays: None.
Objectives: Demonstrate crew/space vehicle/mission support facilities during manned Saturn V/CSM/LM mission. Achieved.
 Demonstrate LM/crew performance. Achieved.
 Demonstrate selected lunar orbit rendezvous mission activities including transposition, docking withdrawal, intervehicular crew transfer, EVA, SPS and DPS burns, and LM active rendezvous and docking. All achieved except EVA (because of Schweickart's illness, most EVA activities were canceled).
 Assess CSM/LM consumables use. Achieved.

APPENDIX C

- Parameters: Apogee, 192 kilometers; perigee, 190 kilometers; first manned Apollo docking, 03:01:59 MET; first docked SPS burn, 05:59:01 MET; first Apollo EVA, 72:53:00 MET; first manned Apollo undocking, 92:39:36 MET; first manned LM to CSM docking, 99:02:26 MET; landing point, 23°12.5'N, 67°56'S; miss distance, 4.8 kilometers; time, 13 March at 12:01 p.m. EST; MET, 241:00:54.
- Recovery: Crew on board U.S.S. *Guadalcanal* at 12:45 p.m. EST; spacecraft aboard ship at 02:13 p.m.

Apollo 10 (AS-505, lunar-orbital)

- Launch: 18 May 1969, Complex 39B, ETR, 12:49:00 a.m. EDT.
Vehicle: Saturn V.
Payload: CSM-106, LM-4.
Crew: Thomas P. Stafford, John W. Young, and Eugene A. Cernan.
Delays: None.
Objectives: Demonstrate performance of LM and CSM in lunar gravitational field. Achieved.
Evaluate CSM and LM docked and undocked lunar navigation. Achieved.
- Parameters: Apogee, 190 kilometers; perigee, 184 kilometers; translunar injection, 02:39:21 MET; maximum distance from earth, 399 194 kilometers; first CSM-LM docking in translunar trajectory, 03:17:37 MET; lunar orbit insertion, 75:55:54 MET; first LM undocking in lunar orbit, 98:11:57 MET; first LM staging in lunar orbit, 102:45:17 MET; first manned LM-CSM docking in lunar orbit, 106:22:02 MET; transearth injection, 137:36:29 MET; landing point, 15°2'S, 164°39'W; miss distance, not available; time, 26 May at 12:52 a.m. EDT; MET, 192:03:23.
- Recovery: Crew on board U.S.S. *Princeton* at 01:31 p.m. EDT; spacecraft aboard ship at 02:28 p.m.

Apollo 11 (AS-506, lunar landing)

- Launch: 16 July 1969, Complex 39A, ETR, 09:32:00 a.m. EDT.
Vehicle: Saturn V.
Payload: CSM-107, LM-5.
Crew: Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin, Jr.
Delays: None.
Objectives: Perform manned lunar landing and return mission. Achieved.
- Parameters: Apogee, 186 kilometers; perigee, 183 kilometers; translunar injection, 02:44:26 MET; maximum distance from earth, 389 645 kilometers; lunar orbit insertion, 75:50:00 MET; lunar landing, 102:33:05 MET (20 July at 04:17 p.m.

APOLLO FLIGHT PROGRAM

EDT); first step on moon, 10:56:15 p.m. EDT; end of EVA, 111:39:13 MET (01:09 a.m.); liftoff from moon, 124:22:00.8 MET (1:54 p.m.); LM-CSM docking, 128:03:00 MET; transearth injection, 135:23:52.3 MET; earth landing, 13°19'N, 169°9'W; miss distance, not available; splash-down time, 24 July at 12:50 p.m. EDT; MET, 195:18:35.

Recovery: Crew on board U.S.S. *Hornet* at 01:53 p.m. EDT; spacecraft aboard ship at 03:50 p.m.

Appendix D

Apollo 11 Experiments

EARLY APOLLO SCIENTIFIC EXPERIMENTS PACKAGE (EASEP)

The *Apollo 11* scientific experiments for deployment on the lunar surface near the touchdown point of the lunar module were stowed in the lander's scientific equipment bay at the left rear quadrant of the descent stage looking forward.

The early Apollo scientific experiments package was carried only on this flight; subsequent Apollo lunar landing missions carried the more comprehensive Apollo lunar surface experiments package.

EASEP consisted of two basic experiments: a passive seismic experiments package (PSEP) and a laser ranging retroreflector (LRRR). Both experiments were independent, self-contained packages that weighed a total of 77 kilograms and occupied 0.34 cubic meters of space.

PSEP used three long-period seismometers and one short-period vertical seismometer for measuring meteoroid impacts and moonquakes. Data gathered would be useful in determining the interior structure of the moon; for example, does the moon have a core and mantle like the earth? The seismic experiment package had four basic subsystems: a structure/thermal subsystem for shock, vibration, and thermal protection; an electrical power subsystem generating 34 to 36 watts by solar panel array; a data subsystem to receive and decode Manned Space Flight Network uplink commands and downlink experiment data and to handle power switching tasks; and a passive seismic experiment subsystem to measure lunar seismic activity and to detect inertial mass displacement.

The LRRR experiment was a retroreflector array, made from cubes of fused silica, with a folding support structure for aiming and aligning the array toward the earth. Laser ranging beams from the earth were reflected back to their point of origin for precise measurement of earth-moon distances, motion of the moon's center of mass, lunar radius, and earth geophysical information.

Earth stations that beamed lasers to the LRRR included the McDonald Observatory, Fort Davis, Texas; Lick Observatory, Mount Hamilton, California; and the Catalina Station of the University of Arizona. Scientists in other countries also bounced laser beams off the LRRR.

APOLLO 11 EXPERIMENTS

Principal investigators for these experiments were Dr. Carroll C. Alley, University of Maryland (LRRR), and Dr. Gary V. Latham, Lamont Geological Observatory (PSEP).

APOLLO LUNAR RADIOISOTOPIC HEATER (ALRH)

An isotopic heater system, built into the passive seismometer package that the *Apollo 11* crew left on the moon, protected the seismic recorder during frigid lunar nights.

The heater, developed by the Atomic Energy Commission, was the first major use of nuclear energy in a manned space flight mission. Each of the two heaters was fueled with 34 grams of plutonium 238. Heat was given off as the well-shielded radioactive material decayed. During the lunar day, the seismic devices sent back to the earth data on lunar seismic activity, or moonquakes. During the 340-hour lunar night, when temperatures dropped as low as -173 degrees C, the 15-watt heaters kept the seismometer at a minimum of -54 degrees C. Exposure to lower temperatures would have damaged the instrument.

The heaters were 7.6 centimeters in diameter, 7.6 centimeters long, and weighed 57 grams each, including multiple layers of shielding and protective materials. The complete seismometer package weighed 45 kilograms. Both heaters were mounted in the seismic package before launch. During the lunar surface walk, the lunar module pilot transported the package a short distance away and set up the equipment. There was no handling risk to the crew. The plutonium fuel was encased in various materials chosen for radiation shielding and for heat and shock resistance. These materials included a tantalum-tungsten alloy, a platinum-rhodium alloy, titanium, fibrous carbon, and graphite, with an outer layer of stainless steel.

Extensive safety analyses and tests were performed by Sandia Laboratories at Albuquerque, New Mexico, to determine the effects of an abort or any conceivable accident in connection with the moon flight. The safety report by the Interagency Safety Evaluation Panel, made up of representatives of NASA, the AEC, and the Department of Defense, concluded that the heater presented no undue safety problem to the general population under any accident condition deemed possible for the Apollo mission.

Appendix E

Apollo 11 Lunar Samples

Three categories of samples were brought back by the *Apollo 11* crew: contingency, bulk, and documented (or core) samples. Neil Armstrong collected contingency samples first—about one kilogram of surface material—being careful to get far enough away from the lunar module that the soil would not have been contaminated by the residue from the descent engine exhaust. He sealed this sample in a plastic bag.

For the second category, the bulk sample, one of the two special rock boxes was filled, using a scoop. Not much attention was given to varying selection, since the objective was merely to collect an adequate amount of material for investigation upon return to the earth. But even here, Armstrong did better than expected, gathering 11 rocks of more than a hundred grams each (the largest weighing nearly a kilogram) some distance away from the base of the lander.

When the activity outside the lunar module fell 15 minutes behind schedule, the lunar sample investigators back on earth worried that the crew might not be able to obtain the documented sample, the third category. Fortunately, the smooth functioning of the life support system and the low metabolic usage of the pilots permitted the extension of the extravehicular period. While Edwin Aldrin collected the two core samples (to study the stratification of subsurface material), Armstrong hurriedly gathered 25 more rock specimens, using tongs to pick them up.

The two boxes were sealed and placed in the lunar module, transferred to the command module after the docking, pulled out on the deck of the aircraft carrier, put in the mobile quarantine facility, and flown to Houston, arriving at the Lunar Receiving Laboratory on 25 July 1969.

The bulk and documented samples were placed within a double biological barrier (vacuum chamber and special cabinets), which made handling and working with the materials difficult. (Contingency sample material was put in a nitrogen cabinet, where working conditions were not so restrictive.) Ordinarily

APOLLO 11 LUNAR SAMPLES

simple laboratory tasks, such as photographing and weighing, were very complex. But the boxes were opened in the vacuum chamber and the rocks were examined, described, photographed, weighed, and chipped. More than 21 kilograms of samples were brought back: one-third in rock fragments of one centimeter or more in diameter and two-thirds in smaller particulate material (soil).

Preliminary work on the samples began in the laboratory on 26 July 1969, and specimens of lunar materials were released to more than 140 principal investigators on 12 September. During the 50-day interim, the set period of quarantine, members of NASA's Preliminary Examination Team (among them, E. M. Shoemaker, N. G. Bailey, R. M. Batson, D. H. Dahlem, T. H. Foss, Maurice Grolier, E. N. Goddard, M. H. Hait, H. E. Holt, K. B. Larson, J. J. Rennilson, G. G. Schaber, David Schleicher, H. H. Schmitt, R. L. Sutton, G. A. Swann, A. C. Waters, and Mareta West) tested the materials.

The team's summary report stated that an unexplained erosion process, "unlike any process so far observed on earth," on the lunar surface—shown in photographs from the Ranger, Orbiter, and Surveyor programs—had been confirmed during examination of the samples in the laboratory.

Chemical composition of the fines (powdered material) and igneous rocks (fire-made), according to the report, was different from that of any known terrestrial rock. The team was also of the opinion that there was a "good chance that the time of crystallization of some of the Apollo 11 rocks may date back to times earlier than the oldest rocks on earth."

Apollo 11 had landed in the southwestern part of Mare Tranquillitatis, 0.67 degrees north latitude and 24.39 degrees east longitude. This region is crossed by relatively faint rays, spreading out from large craters in that sector of the moon. There is a possibility that these rays might contain fragments from Craters Theophilus, Alfraganus, and Tycho—although the closest of these, Alfraganus, is 160 kilometers away.

At the landing site, particles ranged from those too small to be seen with a naked eye to two-thirds of a meter in diameter. The surface material formed a layer called the lunar regolith (mantle), porous and weakly coherent on the surface but more densely packed underneath. The bulk of the mantle in the landing area was of fine particles, although there were rock fragments on top of and in the soil.

Around the lunar module, the crew observed that the rocks were varied in shape and that most of them were embedded in the soil to some degree. A majority of the rocks examined had rounded tops, but the bottoms of these same rocks usually had either flat areas or irregular angular shapes. To Armstrong, one rock (not brought back) resembled a distributor cap. He dislodged it with a kick and saw that the buried portion was larger than the exposed end and was angular in shape.

The evaluation team used the term "rock" for any fragment larger than one centimeter in diameter and "fines" for anything smaller. It divided the samples into four types:

- A. Fine-grained vesicular (with small cavities or bubbles probably formed by gas) crystalline igneous rock.

APPENDIX E

- B. Medium-grained vuggy (having larger cavities than in the vesicular samples) crystalline igneous rock.
- C. Breccia (fine materials embedded with sharp fragments), a mixture of different rock types, minerals, and glass.
- D. Fines (crushed powder).

According to the team, the crystalline rocks were volcanic in origin, with pyrogenic mineral assemblages (produced by heat) and gas cavities. The samples contained clinopyroxene, plagioclase, ilmenite, troilite, iron, and olivine. Two surface features that appeared to be common to all rocks were small pits lined with glass and glass spatters not necessarily associated with the pits. Moreover, the exterior of the rocks was lighter in color than the interior, which indicated to the team a microfracturing process of the surface crystals.

The glassy deposits were interesting to the crew and to the investigators. On the moon, Armstrong said, the glass looked like balls of solder that had hit the surface in a fluid state and then hardened. He said the glass appeared to have a metallic luster with multicolored reflections. In the laboratory, the team observed that some glass particles (the samples ranged in size from 10 millimeters to less than 10 microns) were colorless and others were brown, red, green, or black. The brown were the most abundant.

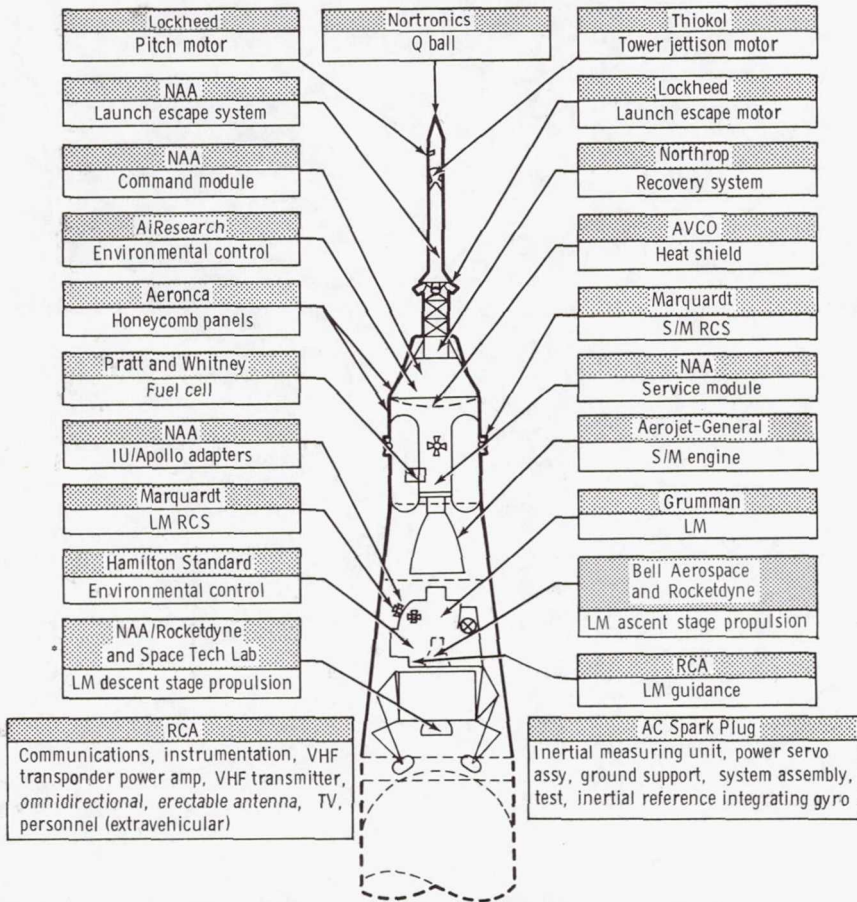
One noticeable feature of the rocks was the rounding of one or more edges and corners. In the softer materials, the breccias, rounding was more pronounced than on the harder crystalline rocks. There were coarser grains poking out of the breccia formations, indicating that the surface had earlier been surrounded by finer grains that had subsequently eroded.

Neither core sample showed any signs of stratification. One of the two did have a lighter zone about six centimeters from the top, but a megascopic (magnified) examination revealed little difference in the lighter and darker materials.

During the preliminary examination, the team conducted microscopic studies, trying to find any living, previously living, or fossilized material. No such material was found in any case. Some of the samples were subjected to germ-free mice, fish, quail, shrimp, oysters, other invertebrates, tissue cultures, insects, plants, and paramecia. There was no evidence that any pathogens were present.

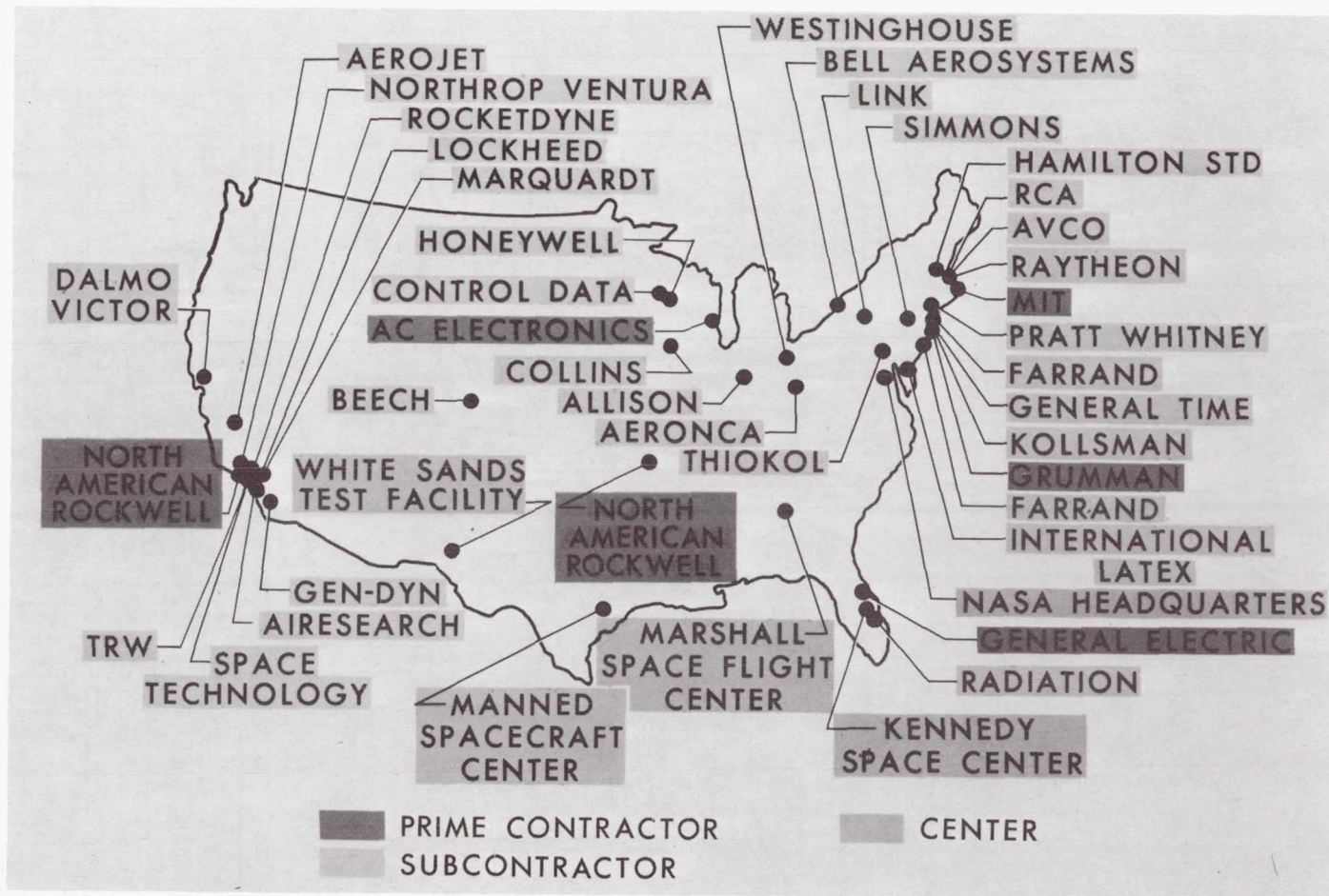
Appendix F

Major Spacecraft Component Manufacturers



Honeywell Company	Collins Radio	Link	Beech Aircraft	Bell Aerosystems
Stabilization, control	Telecommunications	Spacecraft mission simulators	Supercritical gas storage	RCS positive expulsion fuel tanks
Allison and Airite Products	Radiation Inc.	Simmonds Precision Products	RCA	Westinghouse Electric
Fuel components	Telemetry data processing for Apollo S-II stage	Propellant mixture controls	TV cameras, main communications antenna	Static inverter
Elgin National Watch	RCA	MIT	Raytheon	Kollsman Instrument
Sequencer	Radar, engineering services	Associate prime-guidance, navigation	Computer	Optics

* STL named sole contractor January 1965.



Apollo spacecraft contractors with contracts and subcontracts \$5 000 000 and more.

Appendix G

Apollo Program Responsibilities of the Manned Space Centers

MANNED SPACECRAFT CENTER

The Manned Spacecraft Center, Houston, Texas, was responsible for design, development, fabrication, qualification, acceptance testing, and delivery of the Apollo spacecraft, associated ground support equipment, and assigned experiments; planning all Apollo missions; controlling the flight phase of the missions, including developing ground equipment necessary for mission control not provided by other centers; selecting, training, and assigning flight crews; developing procedures as needed for spacecraft guidance, checkout, and mission control; establishing prelaunch requirements for test, checkout, and inspection of Apollo spacecraft; and planning the implementation of the lunar science program.

In carrying out these assignments, the center performed the following functions in the listed areas:

I. *Hardware*

a. Provided detailed specifications, design, manufacture, checkout, test, reliability and quality control, and acceptance of Manned Spacecraft Center- (Houston-) developed hardware, not including test and checkout functions at the launch site by the Kennedy Space Center.

b. Developed and delivered to Kennedy flight-qualified spacecraft and listings or discussions of appropriate procedures, pertinent data, and support equipment.

c. Provided detailed specifications, design, development, fabrication, qualification, acceptance testing, and delivery of experiments flight hardware and associated specialized ground equipment for experiments approved by the Manned Space Flight Experiments Board.

d. Controlled the receipt and stowage of scheduled and approved flight crew personal equipment at the launch center and provided Kennedy with a list of this equipment.

Abstracted from "Center Responsibilities in the Apollo Program," NASA Apollo Program Directive No. 33, 8 Nov. 1967.

APPENDIX G

II. *Configuration Control*

a. Established and controlled configuration of spacecraft hardware, procedures, and associated support equipment at each stage of preparation or test in the factory and at the test or launch sites.

b. Provided and maintained a list of acceptable items and materials entering the spacecraft during checkout and launch.

III. *Test and Checkout*

a. Established and maintained test and checkout requirements, specifications, and criteria for factory or test site acceptance and launch site preparation of all Houston-developed hardware and procedures.

b. Provided written approval of Kennedy test and checkout plans.

c. Reviewed the adequacy of Kennedy test procedures.

d. Determined functional performance and flight readiness of flight hardware and provided any technical assistance or data required by Kennedy in preparing hardware for flight.

e. Provided requirements and criteria to Kennedy for ensuring flight readiness of experiment flight hardware.

IV. *Reliability and Quality Assurance*

a. Provided quality control requirements and inspection criteria for Houston-developed hardware for use at the factory, test, and launch sites.

b. Audited contractor factory and test site performance, in accordance with requirements and criteria, and participated, when appropriate, in audits conducted by Kennedy at the launch site.

c. Determined corrective action for Houston-developed hardware that had failed, malfunctioned, or performed outside of specifications.

V. *Systems Engineering*

Provided technical representation on design and operations inter-center panels or working groups established by the Apollo Program Office.

VI. *Operations*

a. Developed flight techniques, procedures, and hardware for the Mission Control Center.

b. Developed objectives, plans, and rules to support Apollo mission assignments.

c. Conducted flight operations.

d. Obtained from Kennedy the necessary checkout and launch operational requirements for incorporation into Houston-designed hardware.

e. Worked with the Department of Defense in planning recovery support.

VII. *Flight Crew*

a. Provided trained flight crews and personal equipment for manned missions.

CENTER RESPONSIBILITIES

b. Directed all astronaut activities, except for flight hardware testing at Kennedy.

c. Developed and operated flight crew training simulators and equipment at Houston or the Cape.

VIII. *Science*

Planned and implemented a lunar science program for Apollo, including site selection, lunar science operations, Lunar Receiving Laboratory operations, and lunar sample analyses.

IX. *Management (General and Specific Responsibilities)*

a. *General*

1. Ensured adequate reflection of Apollo's manpower and institutional support needs in Houston's resource requirement plans, schedules, and budgets.

2. Ensured timely institutional support for Apollo.

3. Developed and operated center facilities in support of Apollo.

4. Established detailed schedules for Houston-developed hardware, procedures, associated equipment, and operational activities to ensure meeting Apollo program plans.

b. *Medical*

1. Provided medical surveillance and support for the astronauts during all phases of the Apollo program and at any location.

2. Evaluated the medical data obtained during manned tests to ensure that the acceptability of equipment performance was properly interpreted and reflected in the postflight mission reports.

3. Provided for the development and implementation of medical disaster plans associated with tests of Apollo hardware at the Houston location.

c. *Safety*

1. Provided written approval of Kennedy criteria for determining hazardous operations at the launch site.

2. Reviewed and approved any Kennedy test and checkout procedures in which flight crews participated.

GEORGE C. MARSHALL SPACE FLIGHT CENTER

The George C. Marshall Space Flight Center, Huntsville, Alabama, was responsible for design, development, fabrication, qualification, acceptance testing, and delivery of the Saturn launch vehicles, including engines, associated ground support equipment, and assigned experiments; furnishing mission planning data from the standpoint of overall vehicle performance; providing launch vehicle data and procedures for launch vehicle guidance and checkout; establishing prelaunch requirements for testing, checkout, and inspection of Saturn launch vehicles; and supporting launch and flight operations as requested by Houston and the Cape.

In carrying out these assignments, the center performed the following functions in the listed areas:

APPENDIX G

I. *Hardware*

a. Provided detailed specifications, design, manufacture, checkout, test, reliability and quality assurance, qualification, and acceptance testing of Marshall-developed hardware, not including test and checkout functions at the launch site by Kennedy.

b. Developed and delivered to Kennedy flight-qualified launch vehicles and associated procedures, data, and support equipment.

c. Provided detailed specifications, design, development, fabrication, qualification, acceptance testing, and delivery of flight hardware for experiments approved by the Manned Space Flight Experiments Board and assigned to Marshall by the Apollo Program Director.

d. Provided logistic support planning and implementation at factory, test, and launch sites for Marshall-controlled hardware.

II. *Configuration Control*

a. Established and controlled configuration of launch vehicle, hardware, associated procedures, and support equipment at each stage of preparation at the factory, test, and launch sites.

b. Provided criteria to Kennedy for controlling equipment, tools, and materials entering or leaving the launch vehicle stages or the instrument unit during launch site preparations and operations.

III. *Test and Checkout*

a. Established and maintained test and checkout requirements, specifications, and criteria for factory or test site acceptance and launch site preparation of Marshall-developed hardware.

b. Reviewed factory, test site, and launch site test requirements, checkout plans, and procedures to ensure adequate testing of Marshall-developed hardware.

c. Reviewed the adequacy of Kennedy test procedures.

d. Provided requirements and criteria to Kennedy to ensure readiness of experiments flight hardware.

e. Determined the functional performance and readiness of flight hardware.

f. Provided technical assistance or data needed by Kennedy in preparing hardware for flight.

g. Determined the flight readiness of the launch vehicle.

IV. *Reliability and Quality Assurance*

a. Provided quality control requirements and inspection criteria for Marshall-developed hardware for use at the factory, test, and launch sites.

b. Audited contractor factory and test site performance and participated, at its own option, in Kennedy-conducted audits at the launch site.

c. Determined corrective action and disposition of Marshall-developed hardware that failed, malfunctioned, or operated outside performance limits.

CENTER RESPONSIBILITIES

V. *Systems Engineering*

- a. Provided technical representation on design or operations inter-center panels or working groups established by the Apollo Program Office.
- b. Provided overall integrated space vehicle systems analyses and criteria for operational requirements and limitations for handling, checkout, and flight as required by the manned space flight centers.
- c. Operated the Manned Space Flight Interface Documentation Repository.

VI. *Operations*

- a. Developed objectives and plans to support Apollo mission assignments.
- b. Provided real-time mission support as requested by the Houston and Cape centers.
- c. Provided input and comment on Kennedy Launch and Manned Spacecraft Center flight rules.
- d. Obtained operational requirements for checkout and launch from Kennedy for incorporation into Marshall-designed hardware.
- e. Identified Marshall operational support requirements.

VII. *Flight Crews*

Provided instructions and materials for training and familiarizing flight crews with Saturn launch vehicles.

VIII. *Science*

None.

IX. *Management (General and Specific Responsibilities)*

a. *General*

1. Ensured adequate reflection of Apollo manpower and institutional support needs in Marshall's resource requirement plans, schedules, and budgets.
2. Ensured institutional support for Apollo on a timely basis.
3. Developed and operated center facilities in support of Apollo.
4. Established detailed schedules for Marshall-developed hardware, procedures, associated equipment, and operational activities to meet Apollo program plans.
5. Provided liquid-hydrogen-fuel management for Marshall and Kennedy.

b. *Medical*

Developed and implemented medical disaster plans associated with tests of Saturn launch vehicle hardware at Marshall.

c. *Safety*

Provided written approval of Kennedy-developed criteria for determining hazardous operations at the launch site.

APPENDIX G

JOHN F. KENNEDY SPACE CENTER

The John F. Kennedy Space Center, on the east coast of Florida at Cape Canaveral, was responsible for developing and operating launch and industrial facilities and associated ground support needed for Apollo and for the assembly, test, inspection, checkout, and launch of Apollo-Saturn space vehicles at the launch site.

In carrying out these assignments, the center performed the following functions in the listed areas:

I. *Hardware*

a. Provided detailed specifications, design, manufacture, checkout, test, reliability and quality assurance, qualification, and acceptance of Kennedy-developed hardware.

b. Developed and delivered qualified ground support equipment associated with launch facilities and not provided by Houston or Huntsville.

c. Developed and operated ground communications, computation, and instrumentation systems and equipment for conducting launch operations.

d. Protected flight hardware and associated ground equipment from contamination, corrosion, or damage that might have resulted from environment, housekeeping, procedures, or human error. Reported any incidents of such damage to Houston or Huntsville centers, as appropriate.

II. *Configuration Control*

a. Established and controlled configuration of Kennedy-developed launch facilities and ground support equipment at each stage of preparation at the factory, test, or launch site.

b. Maintained configuration control of Houston- and Huntsville-developed hardware, obtaining approval from those centers before making any configuration changes to spacecraft, launch vehicle, or associated ground support equipment supplied by the centers.

c. Secured, after testing, approval from Huntsville or Houston, for the replacement of any failed parts.

d. Controlled everything entering or leaving the spacecraft during checkout at the launch site, in accordance with a list of acceptable items provided by Houston.

e. Controlled all tools, equipment, and materials entering or leaving the launch vehicle stages and the instrument unit during operation at the launch site, in accordance with criteria provided by Huntsville.

III. *Test and Checkout*

a. Conducted assembly, checkout, and launch of flight hardware for Apollo missions, and assembly, checkout, and operation of necessary ground support equipment.

b. Controlled all personnel participating in test and checkout activities, including representatives from Houston and Huntsville centers.

c. Provided requirements, specifications, criteria, and procedures for test and checkout of Kennedy-developed equipment.

CENTER RESPONSIBILITIES

d. Provided test and checkout plans to meet Houston and Huntsville requirements and to verify the launch facility, Manned Space Flight Network, and launch crew readiness and range and safety requirements.

e. Obtained Houston and Huntsville approval before changing and implementing test and checkout plans.

f. Made final determination on safety and adequacy of test and checkout procedures.

g. Obtained approval from Houston and Huntsville on waivers and deviations in all aspects of test and checkout functions when unable to meet prior requirements.

h. Determined readiness of procedures and flight hardware.

i. Determined readiness of inflight experiments equipment.

j. Controlled receipt, storage, and readiness of all Government-furnished equipment except crew personal equipment (suits, etc.).

k. Provided routine troubleshooting and maintenance on Huntsville- and Houston-developed equipment, in accordance with requirements, specifications, and criteria provided by those centers.

l. Provided an assessment of the readiness of the launch complex, flight hardware, and procedures to the Flight Readiness Review Board.

IV. *Reliability and Quality Assurance*

a. Provided quality control requirement and inspection criteria for Kennedy-developed hardware for use at factory, test, and launch sites.

b. Audited contractor factory and test site performance on Kennedy-developed hardware.

c. Determined corrective action and disposition of Kennedy-developed hardware that failed, malfunctioned, or operated outside performance limits.

d. Generated quality control requirements to meet Huntsville, Houston, and Kennedy needs in verifying launch facility and launch vehicle readiness and range and safety requirements. Obtained approval from Huntsville and Houston, if appropriate, before implementing quality control plans.

e. Conducted quality control inspections and audits of contractor activities at Kennedy, inviting Huntsville and Houston representatives to participate where appropriate.

f. Obtained approval from Huntsville or Houston to disassemble any flight hardware that had been accepted at either the factory or test site.

g. Advised the other two centers of any launch preparation problems involving flight readiness of hardware.

h. Conducted failure analyses when requested by Houston or Huntsville.

i. Participated in flight hardware acceptance reviews and offered recommendations to either Huntsville or Houston about accepting the hardware for shipment to the launch site.

V. *Systems Engineering*

Provided representation on design and operations intercenter panels or working groups established by the Apollo Program Office.

APPENDIX G

VI. *Operations*

- a. Identified Kennedy operational support requirements.
- b. Provided data to Huntsville or Houston for incorporation in Program Support Requirements Documents.
- c. Conducted launch operations.
- d. Developed launch plans and rules.

VII. *Flight Crews*

Coordinated and directed astronaut activities during crew participation in Kennedy tests of flight hardware, although the pilots had the final word in matters pertaining to their safety.

VIII. *Science*

None.

IX. *Management (General and Specific Responsibilities)*

a. *General*

1. Ensured adequate reflection of Apollo program needs for manpower and institutional support in the center's resource requirements plans, schedules, and budgets.
2. Ensured timely institutional support for Apollo.
3. Controlled activities of Apollo contractors at Kennedy, with the exception of those directly associated with astronaut training.
4. Developed and operated center facilities needed for Apollo.
5. Established detailed schedules for Kennedy-developed hardware, procedures, and associated equipment to meet Apollo program plans.

b. *Medical*

Developed and implemented medical disaster plans associated with assembly, checkout, and operations at launch site.

c. *Safety*

1. Served as NASA's single point of responsibility for safety at the launch center and provided range safety inputs to Eastern Test Range authorities.
2. Developed criteria for hazardous operations at the launch site and coordinated the criteria with the Houston and Huntsville centers.

Appendix H

Funding—As of 30 June 1969

(in thousands)

Fiscal Year	NASA Total	Apollo Program	
1960	\$ 523 575	Advanced technical development studies	\$ 100
1961	964 000	Advanced technical development studies	1 000
1962	1 671 750	\$160 000	
		Orbital flight tests	63 900
		Biomedical flight tests	16 550
		High-speed reentry tests	27 550
		Spacecraft development	52 000
1963	3 674 115	\$617 164	
		Command & service modules	345 000
		Lunar module	123 100
		Guidance & navigation system	32 400
		Instrumentation & scientific equipment	11 500
		Operational support	2 500
		Supporting development	3 000
		Little Joe II development	8 800
		10 Saturn I launch vehicles	90 864
1964	3 974 979	\$2 243 900	
		Command & service modules	545 874
		Lunar module	135 000
		Guidance & navigation system	91 499
		Integration, reliability, & checkout	60 699

APPENDIX H

Fiscal Year	NASA Total	Apollo Program	
1965	4 270 695	Saturn I	187 077
		Saturn IB	146 817
		Saturn V	763 382
		Engine development	166 000
		Apollo mission support	133 101
		\$2 614 619	
		Command & service modules	577 834
		Lunar module	242 600
		Guidance & navigation system	81 038
		Integration, reliability, & checkout	24 763
1966	4 511 644	Spacecraft support	83 663
		Saturn I	40 265
		Saturn IB	262 690
		Saturn V	964 924
		Engine development	166 300
		Apollo mission support	170 542
		\$2 967 385	
		Command & service modules	615 000
		Lunar module	310 800
		Guidance & navigation system	115 000
1967	4 175 100	Integration, reliability, & checkout	34 400
		Spacecraft support	95 400
		Saturn I	800
		Saturn IB	274 185
		Saturn V	1 177 320
		Engine development	134 095
		Apollo mission support	210 385
		\$2 916 200	
		Command & service modules	560 400
		Lunar module	472 500
1968	3 970 600	Guidance & navigation system	76 654
		Integration, reliability, & checkout	29 975
		Spacecraft support	110 771
		Saturn IB	236 600
		Saturn V	1 135 600
		Engine development	49 800
		Apollo mission support	243 900
		\$2 556 000	
		Command and service modules	455 300
		Lunar module	399 600
		Guidance & navigation system	113 000
		Integration, reliability, & checkout	66 600
		Spacecraft support	60 500
		Saturn IB	146 600

FUNDING

Fiscal Year	NASA Total	Apollo Program	
		Saturn V	998 900
		Engine development	18 700
		Apollo mission support	296 800
1969	3 193 559	\$2 025 000	
		Command & service modules	346 000
		Lunar module	326 000
		Guidance & navigation system	43 900
		Integration, reliability, & checkout	65 100
		Spacecraft support	121 800
		Saturn IB	41 347
		Saturn V	534 453
		Manned space flight operations	546 400

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Source Notes
Bibliographical Note
Index

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Chapter 1

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NOTES TO PAGES 271-277

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Six years before Apollo reached its goal in 1969, a cartoon depicted two men standing atop two extremely tall stacks of paper. One man, as he stepped out onto the lunar surface, said to the other: "I told you we would get to the moon." The cartoonist may not have been too far off the mark when one considers the documentation generated by Apollo. Some 200 linear meters of that paper, more than half of it covering the period through the first lunar landing, came to rest in the History Archives of the Johnson Space Center in Houston, Texas. And this small percentage of the whole represents what was left after numerous screenings and cullings by historians, archivists, and editors. These materials were collected in a variety of ways over a period of years.

While the research for this Apollo history was being done, government engineers connected with manned space flight evolved into three-program veterans—Mercury, Gemini, and Apollo. Of these participants, many became pack rats, collecting documents and creating what might be called "desk archives." Much of this material contains engineering marginalia that leads the researcher on to more and more documents, with a snow-balling effect. As the engineers moved to new positions and were forced to clean out their desks, many were happy to find a historical archives function that might preserve some of their more treasured papers. Along with material collected during research and documentary forays by historians, archivists, and editors to NASA Headquarters in Washington and to its other centers scattered over the nation and during visits to institutions and industrial concerns connected with Apollo, these holdings—covering the years 1957

CHARIOTS FOR APOLLO

through 1972 and including letters, memoranda, studies, reports, etc.—became extensive (25 five-drawer filing cabinets).

Another, somewhat similar, collection exists, because NASA like all federal agencies is required to retire its documents to regional Federal Records Centers on a regular schedule. Government paperwork falls into two categories: record, or official, copies that must be retired, and duplicate copies and unofficial working papers that may be retained in reading files as long as they are needed. But even here NASA had to exercise control, sponsoring a spring-housecleaning “Records Roundup” annually to screen and dispose of some of these reading files. The Records Management Officer has encouraged organizational elements to send their reading files to the historian, to gain credit for “destroyed records.” Several major accessions resulted from this procedure.

Among the major additions to the JSC History Archives were the complete Houston Apollo Spacecraft Program Office reading files, covering 1960 through 1972 (17 five-drawer filing cabinets). This collection contains a cross-section of materials on almost every phase, event, or subject of the Apollo program. It includes matter from every organizational element in the spacecraft program office, as well as correspondence from other divisions of the Houston center, from other NASA centers, from NASA Headquarters, and from industry and institutions that worked on Apollo. Research in these files turned up information on technical problems in the program, from the time problems were discovered until they were finally resolved, and on program decisions, failures, and successes. A number of summary documents evaluated Apollo at specific times, to measure performance and progress against costs and schedules.

Research in this extensive collection, by three historians with the help of an editor and an archivist, was a physical, as well as mental, task. Even with the mass of documentation, however, there was no mystery about what subjects would be important in the development of the Apollo spacecraft. For example, it was obvious from the start that the mode issue—how NASA intended to fly men to the moon and back—was a major influence on spacecraft, launch vehicle, and launch preparation, and facility designs. Subjects such as this had generated so much paperwork at so many locations that there is probably enough material to write lengthy monographs on each. Most of the source notes to this volume, therefore, form small bibliographies for the narrative discussions. Again, the historians had to make arbitrary selections of which documents to cite because of the physical limitations on the number of citations possible in one book.

Another source, unique to the writing of contemporary (or near-contemporary) history, added to the archives collection: tape-recorded oral history interviews (two-thirds of them transcribed) of many key program participants. This research began before Apollo reached its goal, continued

BIBLIOGRAPHICAL NOTE

after the program ended, and gave the historians an opportunity to see the hardware at the factory, test, and launch sites. Thus, when the book was written, authors had some personal knowledge of the persons, hardware, and operations. Quite often, these contacts later helped the authors explain the solutions to technical problems in a language that both the writer and the reader could understand. How the engineers settled on the number, arrangement, and folding of the lunar module's legs required several telephone calls to clarify the solution. The answers to who decided which American would be the first to step out onto the lunar surface and why the decision was made required more calls. Such conversations often uncovered more formal documentation on the subject, and the archives continued to grow.

As may be easily discerned, this history of the Apollo spacecraft, and subjects directly related to the spacecraft, represents what might be called the internalist approach. One member of the academic community who reviewed this work commented that he no longer worried that the text would be "court history," presenting events too much from the program participants' point of view. He did, however, complain that the historians had become too intrigued with the mass of available information to "raise their heads out of the files." Other reviewers contended that the historians paid too much attention to outside influences on the program and not enough to the technical descriptions and development of the machines. These diverse comments were appreciated and responded to, in some degree—although not, perhaps, to the satisfaction of either side. We hope we have presented enough of the story of the program, as well as its technical problems and solutions, to capture the interest of the reader whose opinions fall somewhere between the two extremes. At any rate, this history is largely based on a portion of the documents that the Apollo program generated. A listing follows of persons talked with, selected samples of the documentation, and other sources used.

1. PERSONS INTERVIEWED

[Asterisks indicate telephone conversations. Key to abbreviations of affiliations is at the end of the list.]

- | | |
|--------------------------------|---------------------------------|
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| 2. Adams, J. J., NAR | 10. Andrews, Norman W., Grumman |
| 3. Africano, Alfred, NAR | 11. Appelman, Charles,* GE |
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| 6. Altneu, Irwin J., NAR | 13. Atkinson, W. A., MSC |
| 7. Amman, Ernest A., KSC | 14. Atwood, Donald J., AC |
| 8. Anderson, Robert C., TRW | Electronics |

CHARIOTS FOR APOLLO

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16. Barlow, Mel R., Gen. Dynamics
17. Barr, William T., MSC
18. Barton, Richard E.,
MSC-Bethpage
19. Battersby, Frank X.,
MSC-Bethpage
20. Battey, Robert V.,* MSC
21. Battin, Richard H., MIT
22. Beauregard, Albert J., Grumman
23. Beggs, Cal, Hamilton Standard
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25. Benjamin, Warren, TRW
26. Benner, R. L., NAR
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29. Bird, John D., LaRC
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31. Blake, Dan, Gen. Precision
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39. Buhler, Cary, Northrop-Ventura
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MSC-Downey
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63. Dandridge, Manning, Grumman
64. Davis, Hubert P., MSC
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KEY TO ABBREVIATIONS

AC Electronics	AC Electronics Division, General Motors Corp.
Aerojet-General	Aerojet-General Corp., Div., The General Tire and Rubber Co.
AiResearch	AiResearch Manufacturing Co., The Garrett Corp.
Airlock	Airlock, Inc.
ARC	Ames Research Center, NASA
Bell Aerospace	Bell Aerospace Co., Div., Textron Inc.
Bendix	Aerospace Systems Division, The Bendix Corp.
Collins Radio	Collins Radio Co.
David Clark	David Clark Co., Inc.

CHARIOTS FOR APOLLO

Edwards AFB	Edwards Air Force Base, Calif.
FRC	Flight Research Center, NASA (renamed Dryden Flight Research Center in January 1976)
GE	General Electric Co.
GSFC	Goddard Space Flight Center, NASA
Gen. Dynamics	General Dynamics Corp.
Gen. Precision	General Precision Systems, Inc., General Precision Equipment Corp.
Grumman	Grumman Aircraft Engineering Corp.
Hamilton Standard	Hamilton Standard Division, United Aircraft Corp.
Honeywell	Honeywell, Inc.
IBM	International Business Machines Corp.
Int'l Latex	International Latex Corp.
JPL	Jet Propulsion Laboratory, operated by California Institute of Technology for NASA
KSC	Kennedy Space Center, NASA
LaRC	Langley Research Center, NASA
LeRC	Lewis Research Center, NASA
McDonnell	McDonnell Aircraft Corp. (merged into McDonnell Douglas Corp. in April 1967)
Marquardt	The Marquardt Corp.
Martin	Martin Marietta Corp.
MIT	Massachusetts Institute of Technology
MSC	Manned Spacecraft Center, NASA (renamed Johnson Space Center in February 1973)
MSFC	Marshall Space Flight Center, NASA
OSD/DOD	Office of the Secretary of Defense, Department of Defense
NAR	North American Rockwell (North American Aviation, Inc., before September 1967; Rockwell International from February 1973)
NASA Hq.	National Aeronautics and Space Administration Headquarters
Northrop-Ventura	Northrop-Ventura, Northrop Corp.
Philco-Ford	Philco-Ford Corp., Ford Motor Corp.
Raytheon	Raytheon Co.
Rocketdyne	Rocketdyne Division, North American Rockwell (formerly North American Aviation, Inc.)
TRW	TRW Inc.
UCSC	University of California, San Diego

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Index

- Aaron, John W., 280
- "A to G" Apollo missions, 234-35, 250, 256-57, 285, 300, 364
- "H" missions added, 364
- "J" missions added, 364
- Abbey, Gene, 487
- Abbey, George W. S., 230, 258
- Abbott, Ira H. A., 20, 46
- Abernathy, Ralph D., 338
- Ablative rocket engine thrust chambers, 92, 154
- Ablative heatshield. *See* Heatshield, ablative.
- Abort mission, 27, 72, 92, 102, 121, 133-34 ill.-35
- Little Joe II test, 141-42, 183
- LM, 146
- off-the-pad, 183
- Accidents, fatal
- aircraft, 207, 217, 262
- simulation chamber, 217
- spacecraft, xvi, 215-26 ill.-227
- AC Spark Plug Div. (General Motors Corp.), 97, 160, 174
- Ad Hoc Surveyor/Lunar Orbiter Utilization Committee, 185
- Adams, J. J., 487
- Adapter, spacecraft-launch vehicle, 41, 108, 132 ill., 133, 153 ill., 163
- Apollo 6*, 248, 250, 252
- Apollo 7*, 267
- LM, 145, 152
- Advanced Saturn. *See* Saturn launch vehicle.
- Aeroembolism, 239-40
- Aerojet-General Corp. (General Tire & Rubber Co.), 90, 155
- Aerospace Corp., 48, 250
- Africano, Alfred, 487
- Agena (upper-stage booster rocket), 7, 69, 154-55
- Borman comments during *Apollo 8*, 276
- engine explosion, 244
- Gemini missions, 294
- Agnew, Spiro T., 292, 296 ill., 299, 322
- Air Force, U.S., 4, 38, 62, 88, 89, 133, 154
- Arnold Engineering Development Center, 154
- Space Systems Div., 62
- AiResearch Manufacturing Co. (div. of The Garrett Corp.), 90, 157, 196, 209
- Aldrin, Edwin E., Jr. (*see also Apollo 11*), ii-iii ill., iv, 130, 283 ill., 321 ill., 325, 350 ill.-51 ill., 356-57 ill., 365
- Apollo 11* planning, 302, 318-323, 326
- assignments, 262
- Gemini XII*, 208
- LRV versus walking, 364
- Algol solid-propellant rocket motor, 141
- Algranti, Joseph S., 322, 487
- Alldredge, J. Brooks, 487
- Altneu, Irwin J., 487
- Allnutt, Robert F., 330
- "All-up" flight testing, 130, 176, 194, 231, 232
- ALSEP. *See* Apollo lunar surface experiments package.
- American Rocket Society, 86
- Ames, Milton B., Jr., 8
- Ames Research Center, NASA, 3
- Apollo support studies, 92, 94
- lunar guidance system study, 39, 97
- lunar mode issue, 80
- lunar research studies, 8, 12, 26
- spacecraft configuration, 27, 35
- suggested site for manned space flight center, 19, 22
- Amman, Ernest A., 487
- Amster, Warren, 48
- Anders, William A. (*see also Apollo 8*), 130, 282 ill., 283 ill.
- Apollo 11* planning, 318-19
- AS-503, 212, 261
- National Aeronautics and Space Council, 319
- Anderson, Clinton P., 219-20
- Anderson, Frank W., Jr., xvii
- Anderson, Robert C., 487
- Anderson, Roger A., 487
- Andrews, Norman W., 487
- Antennas, space communications
- 9-meter dish, 123
- 26-meter dish, 123
- 64-meter dish 123, 124 ill., 328
- portable lunar surface, 328
- spacecraft, 159
- Apollo 1 (AS-204), 227, 231
- widows' numbering request, 231
- Apollo 1A (number rejected), 231
- Apollo 2 (number rejected), 231
- Apollo 3 (number rejected), 231
- Apollo 4* (AS-501), 231-33 ill., 262

CHARIOTS FOR APOLLO

- achievements, 234, 237, 247
- AS-501, 231
- flight, 232-33
- flight number confusion, 231
- objectives, 232
- SM engine firing 233
- Apollo 5* (AS-204)
 - flight, 242, 244
 - flight preparations, 241-42, 243 ill.
 - objectives, 242, 244
- Apollo 6* (AS-502)
 - flight, 248-49
 - flight preparations, 247-48
 - launch vehicle-spacecraft adapter problem, 248, 252
 - objectives, 247
 - photography, 248, 249 ill.
 - pogo problem, 248, 250-51, 272
 - results, 250-53
 - S-11 stage problems, 248, 252
 - S-IVB stage problems, 249, 252
 - SM engine firings, 249
- Apollo 7* (AS-205; Schirra, Cunningham, Eisele)
 - cabin noise, 268
 - crew illness, 271
 - crew watch arrangement, 269
 - factor in *Apollo 8* decision, 260, 271-72
 - flight, 267-70 ill.-71 ill.
 - flight preparations, 262-64, ill.-67
 - food, 269
 - intravehicular activity, 268-69
 - "magnificent flying machine," 271
 - newsworthiness, 271-72
 - objectives, 266, 271-72
 - photography, 266, 268
 - practice rendezvous, 267
 - SM engine performance, 267
 - sleep, 269
 - support crew innovation, 261
 - television, 266, 269, 270 ill., 271
 - visibility and windows, 268
 - waste management, 268
- Apollo 8* (AS-503; Borman, Lovell, Anders)
 - Apollo 7* results, 260
 - Book of Genesis reading, 281
 - comments about lunar surface, 279-80
 - communications, 279
 - crew illness, 277
 - CSM 103 performance, 281, 283
 - CSM/S-IVB separation, 276-77
 - earth view comments, 277, 278, 366
 - first gravitational crossing, 278
 - flight, 275-82 ill.-83 ill.-84
 - flight preparations, 272-75
 - landing accuracy and recovery, 283-84
 - lunar-orbit decision. *See* Lunar-orbit mission, first manned.
 - lunar orbital flight, 279-81
 - lunar-orbit insertion (LOI), 278-79
 - naming lunar craters, 280
 - objectives, 272-75, 284
 - pogo, 276, 288
 - postflight activities, 284
 - prayer, 280-81
 - SM engine performance, 278-79, 281
 - television, 276, 278, 281, 283 ill.
 - two-phase lunar orbit maneuver, 279, 300
 - vehicle and mission reviews, 272-73
 - world reactions, 281, 366
- Apollo 9* (AS-504; McDivitt, Scott, Schweickart)
 - astronaut head colds, 290
 - call signs, communications, 292
 - cost, 299
 - crew illness, 293, 294, 295
 - crew selection, experience, and training, 290-92
 - effects on future flights, 364
 - extravehicular activity, 295-97 ill.-98
 - flight, 292-97 ill.-300
 - flight preparations, 288-91 ill.-92, 296 ill.
 - flight readiness reviews, 289-90
 - Gemini VI/VII*, influence, 290
 - Gumdrop* (CM-104), 292, 295-97 ill.-99
 - LM-CSM flight separation, 297 ill., 298
 - LM-CSM rendezvous and docking, 287, 290, 293, 297 ill., 298-99
 - mission duration, 299
 - news interest, 292
 - number earth-orbital revolutions, 299
 - objectives, 290-91, 299
 - pogo, 288, 293, 299
 - SM engine firings, 294, 299
 - Spider* (LM-3), 286-87, 295-97 ill.-300, 302
 - descent engine chugging, 298, 300, 302
 - checkout, 295
 - flying qualities, 287
 - separate flight, 297 ill., 298-99
 - spacecraft/S-IVB separation, 293
 - transfer of crew between craft, 293, 294-95, 298, 299
- Apollo 10* (AS-505; Stafford, Young, Cernan)
 - between-spacecraft communications, 310, 311
 - between-spacecraft sightings, 310
 - Charlie Brown* (CM-106), 301, 302-04, 307, 309, 311-12
 - crew rest (sleep), 304, 306
 - crew selection and training, 302
 - crew transfer between craft, 306, 307, 311-12
 - docking, 300, 303, 307, 311
 - DOI, 310
 - dressing and undressing, 307
 - drinking water, food, 304-05

- flight, 303-08 ill.-09 ill.-12
- flight patch, 302
- flight preparations, 288, 300-03
- flight readiness reviews, 301-02
- illness-free crew, 304
- landing site visibility, 309 ill., 310
- lunar landmarks and observations, 301, 305-06, 309 ill., 310
- lunar orbit insertion (LOI), 305-06
- mylar insulation problem, 306, 307
- number of lunar orbits, 312
- objectives, 300-01, 310
- photography, 308-09 ill., 310
- pilot error, 311
- pogo, 303
- public interest, 303, 305
- radar, 301, 307, 310, 311
- S-IVB stage sighting, 305
- Snoopy* (LM-4) 286-87, 298, 301-02, 304, 306-07, 309 ill., 310-12
 - engine firings, 310, 311
- spacecraft rendezvous, 311
- spacecraft/S-IVB stage separation, 303
- spacecraft undocking, 307
- star sightings, 304
- television, 303-05, 308 ill.
- TLI, 303
- two-phase lunar-orbit maneuver, 300
- up-down orientation, 306
- Apollo 11* (AS-506; Armstrong, Aldrin, Collins; *see also Apollo 11* flight planning)
 - adaptation to one-sixth gravity, 345-47
 - Aldrin's lunar walk, ii-iii, iv, 346-49, 350 ill.-51 ill.
 - Armstrong's lunar walk, 346-50 ill.
 - ascent from the moon, 352-53
 - "bag of rocks" quotation, 365
 - biological isolation garments (BIG), 355-56 ill.
 - Columbia* (CM-107) 331, 342, 345, 351 ill., 352-57
 - communications first, 344-45
 - computer alarms, 343
 - crew description of moon, 341, 345, 346-47, 348-49, 353
 - crew rest (sleep), 339, 342, 349, 352, 354
 - CM-LM separation and docking, 339, 342, 353, 358
 - daily news summary, 340
 - Eagle* (LM-15), 331, 341-50 ill.-51 ill.-54
 - earthshine, 341, 349
 - experiments (*see also* Appendix D), 348-49, 351 ill., 363, 365
 - first manned landing on moon, 343-44
 - flag raising, 347
 - flight, ii-iii, iv, xiv, 338-50 ill.-51 ill.-56 ill.-58
 - flight preparations, 313, 338-39
 - "high gate," 343
 - home on the moon, 349, 352
 - illness-free crew, 339
 - influence on *Apollo 12* schedule, 365
 - LM windows, 340, 341, 343-45, 350 ill.-51 ill.-53
 - "low gate," 343
 - Luna 15*, 340
 - lunar dust, 344, 346, 347, 349, 350 ill., 353
 - lunar landing site, 337, 341, 343-46, 350 ill.-51 ill., 352, 365
 - lunar orbit insertion (LOI), 341
 - Lunar Receiving Laboratory, 354, 356 ill., 359
 - lunar-orbit rendezvous, 353
 - lunar sample collection (*see also* Appendix E), 346, 348-49
 - lunar soil, 344, 346, 347
 - men on the moon, 344-50 ill.-51 ill.-52
 - mission duration, 355, 358
 - mission sequence, 358
 - mobile quarantine facility (MQF), 356 ill., 357, 359
 - modular equipment stowage assembly (MESA), 341
 - most remembered mission, 365-66
 - Nixon phone call and world tour, 347-48, 354
 - objectives, xiv, 314, 357, 365
 - peculiar odor in tunnel, 339 353
 - photography, 341, 342, 347, 348, 351 ill., 354, 355, 359
 - plaque, 330, 331 ill., 347
 - portable life support system (backpack), 345-46, 349, 350 ill., 351 ill.
 - practice lunar-ascent countdown, 345
 - probe and drogue, 339, 340, 342, 353
 - public interest, 326, 338 340, 357
 - quarantine, 333-35 ill., 357
 - radar, 342
 - reentry and recovery, 355-56 ill.-59
 - results, 365-66
 - Sea of Fertility, 341
 - SM engine firings, 339, 340, 341, 354
 - television, 340, 341, 346, 347-48 350 ill.-51 ill., 354, 357
 - "That's one small step," 346
 - "The Eagle has wings," 342
 - "The Eagle has landed," 344
 - Tranquility base. *See* lunar landing site.
 - unidentified object, 341
 - world tour, 357
- Apollo 11* flight planning, 313-34
 - American flag, 314, 329-30
 - Apollo lunar surface experiments package (ALSEP), 319-21 ill., 363
 - ascent from moon, 317-18
 - back contamination provisions, 333-34

CHARIOTS FOR APOLLO

- biological isolation garment (BIG), 333
- call signs, 302-03, 331
- communications and tracking, 334
- Columbia* (CM-107), 331
- crew patch, 331
- crew selection and training, 313-14, 318, 321 ill.-25 ill.-26
- Eagle*, (LM-5), 331
- early Apollo scientific experiments package (EASEP), 320
- EMU, 323-24
- first man on moon decision, 319, 321-22
- flight readiness reviews, 334
- lighting levels required, 328-29
- LM checkout on moon, 317
- LM landing and takeoff angle, 317
- LM overturn possibilities, 317
- Lunar Receiving Laboratory, 332-33
- lunar descent worries 316-17
- lunar gravity. *See* Gravity, lunar.
- lunar landing approach procedures, 316-17, 337
- lunar landing training vehicle (LLTV), 322-23
- lunar surface operations demonstration, 319-20
- lunar surface stay decision, 324-26
- no claims on moon, 330
- objectives, 314
- photography, 328-29
- plaque, 330, 331 ill.
- public affairs activities, 326-31
- recovery and quarantine, 333-34
- Sea of Tranquility, 317, 337
- space exploration treaty, 330
- spacecraft "walk-down" team, 334
- special LM-2 tests, 334
- symbols and symbolism 314, 329-31
- television, 329
- walks, lunar surface. *See* Walks, lunar surface.
- Apollo 12* (Conrad, Bean, Gordon), 365, 366
- Apollo 13-17*, 366
- Apollo 204. *See* Apollo-Saturn 204.
- Apollo 204 Review Board, 218-25, 232
 - findings, 221-22, 224-25
 - investigation, 218-22, 224
 - membership, 219
 - panels, 219, 220
 - report 221-22, 224, 228
- Apollo Applications Program (later renamed Skylab), 188, 189, 229, 255, 362
- Apollo Back Contamination Control Panel, 333
- Apollo CM Source Evaluation Board, 42-44
- Apollo Crew Safety Review Board, 238, 240-41
- Apollo Executives Committee, 129, 218, 273-74
- Apollo lunar surface experiments package (ALSEP), 202, 319-21 ill., 363-64
- Apollo mission A-003, 183
- Apollo mission A-004, 190
- Apollo Mission Planning Task Force. *See* Design Reference Mission.
- Apollo program, xii, xiii-xv, 15, 19-26, 29-31, 33, 37, 41, 46, 56, 110-11, 118, 129, 167, 219, 357
 - "A to G" lunar landing plans, 234-35, 250, 256-57, 285
 - accomplished goals, 361, 365-66
 - all-up decision impact, 130-31
 - announced, xiii, 15
 - approved, 29-30
 - AS-204 accident impact, 227, 230
 - benchmark for comparisons, 366
 - complaints against, 131, 189, 219-20, 361-62
 - contractor use, 19
 - contracts. *See* Contracts, Apollo, and Appendix F.
 - costs, *See* Cost of Apollo program and Appendix H.
 - flight intervals, 255, 286, 365
 - flight numbering confusion 231-32
 - follow-up program possibilities, 187-188, 362
 - "H" missions, 364
 - "J" missions, 364
 - management devices. *See* Management devices, space program.
 - management personnel shakeup, 224
 - objectives, 121-22, 125-26, 136, 361, 365-66
 - priority, 110-11
 - pros and cons, 131, 361
 - recovery from AS-204 accident, 228-30, 231-32
 - support, xiii, 34, 361-62
 - to include all manned lunar landing missions, 362
 - worker morale, 256
- Apollo Program Development Plan, 168
- Apollo Projects Office, 21
- Apollo-Saturn 201 mission, 190-92 ill.-94, 209
 - Apollo 1A number rejected, 231-32
 - countdown and flight, 191-92 ill.-93
 - CSM-009, 190-91
 - objectives, 191, 193
 - recovery, 193
 - results, 192-93
- Apollo-Saturn 203, 190, 193
 - Apollo 2 numbering rejected, 231-32
 - objectives, flight, and results, 194
- Apollo-Saturn 205, 190, 193
 - Apollo 3 numbering rejected, 231-32
 - objectives and flight, 193-94

- Apollo-Saturn 204, 190, 231
 - accident investigation, 216 ill.-27
 - Apollo 1, 231
 - Apollo 204 review board. *See* Apollo 204 Review Board.
 - attempted rescue, 215-16
 - cost and delay caused by accident, 230
 - crew announced, 208
 - crew memorial services, 217
 - CSM-012, 209-10 ill.-11, 213-16 ill., 220-22, 224-26
 - delayed, 211
 - Design Certification Review, 211
 - experiments, 209
 - fire, 215-16 ill.-17, 220-21, 224, 261
 - launch-pad test procedures, 230, 239
 - objectives, 208-09
 - plugs out test, 213-15, 217
 - possible causes of accident, 221-22, 224, 225
 - scheduled launch, 221
- Apollo-Saturn 205 (*see also* Apollo 7), 209
 - AS-208, 211, 261
 - canceled, 211, 229-30, 261
 - crew named, 209, 212
 - objectives, 209, 212
 - rescheduled, 211, 261
- Apollo-Saturn 206A, 175-76
- Apollo-Saturn 207, 205-06
- Apollo-Saturn 208, 205-06
 - AS-205, 211, 261
- Apollo-Saturn 501 (*see also* Apollo 4), 231, 232
- Apollo-Saturn 502 (*see also* Apollo 6), 248
- Apollo-Saturn 503 (*see also* Apollo 8), 212, 261
- Apollo-Saturn 504. *See* Apollo 9.
- Apollo-Saturn 505. *See* Apollo 10.
- Apollo-Saturn 506. *See* Apollo 11.
- Apollo Site Selection Board, 185, 364
- Apollo Soyuz Test Project, xiv, 131
- Apollo Spacecraft Development Test Plan, 136
- Apollo Spacecraft Project (Program) Office, 78, 98, 99-100, 108, 120, 256
 - Configuration Control Board, 168, 230
 - Configuration Control Panel, 168
 - organization, 78, 98, 99
- Apollo Systems Specification Book, 121-22
- Apollo Technical Conference. *See* NASA-Industry Apollo Technical Conference, 1961.
- Apollo Trajectory Working Group, 120
- Appleman, Charles, 487
- Appold, Norman C., 13
- Arabian, Donald D., 305
- Armitage, Peter J., 332
- Armstrong, Neil A. (*see also* Apollo 11), 116
 - ill., 351, 356 ill., 357 ill., 365
- Apollo 11 planning, 283 ill., 302, 318, 321
 - ill.-25 ill.-26
 - crew assignment in 1967, 262
 - first man to walk on moon, 346, 350 ill.
 - Gemini VIII, 205
 - LRV versus walking, 364
 - public affairs activities, 327-28
- Armstrong, William O., 487
- Army, U.S. (*see also* Army Ballistic Missile Agency, Corps of Engineers, and White Sands Missile Range), 3, 4
 - Redstone Arsenal, 51-52
- Army Ballistic Missile Agency (ABMA), 3, 5, 14, 62
- Army Biological Laboratories, 204
- Arnold Engineering Development Center, 154, 165, 252
- ARP (Apollo Rendezvous Phase), 69
- Arthur, George R., 26
- Ascent engine, LM, 113, 154-55
 - ablative thrust chamber 154, 200-01
- Apollo 5, 242, 244
- Apollo 9, 298-99
- Apollo 10, 311
- Apollo 11, 352
 - backup model, 200
 - combustion instability, 154-55, 200-01, 232, 237, 244-45
 - contractor, 113, 154, 244-45
 - description, 144, 146, 154
 - fire-in-the-hole 146, 154, 242
 - fuel injector, 176, 201, 244-45
 - lunar launch, 146
 - lunar orbit abort, 146, 154, 242
 - reliability requirements, 154-55
 - test program, 154-55, 175, 200-01, 245
- Ascent stage, LM, 144, 146, 243 ill., 247, 309
 - ill.
 - cabin. *See* Cabin, LM,
 - design, 144-46
 - lunar orbit abort, 146
- Ascent trajectory analysis, lunar, 69, 317, 318
- AstraCo, 65
- Astronauts (*see also* Appendix B), xiv, xv, xvi, 30
 - Apollo training philosophy and flight tasks, 260-61
 - deaths, xv-xvi, 207, 217, 262
 - extravehicular operations, 137, 150, 182, 207, 208, 290-91 ill., 295-97 ill.-98, 345-50-51 ill., 364
 - fifth group, 180, 206
 - first group, 30, 116
 - first man on moon decision, 319, 321-22
 - flight crew titles, 261
 - fourth group, 180
 - Gemini experience, 208
 - lunar surface procedures, 151, 153 ill., 321 ill., 323-25 ill., 326

CHARIOTS FOR APOLLO

- medical factors, 260, 262, 277, 290, 293-95, 304-05, 339
- mission assignments, 208-09, 212, 261-63, 275, 290, 302, 318-19, 365
- pilot or nonpilot, 179-80
- science role, 260-61
- scientist-astronauts, 179-80
- second group, 116, 116 ill.
- selection, 178, 179-80, 206
- spacecraft design and reviews, 148-49, 161
- support team innovation, 261
- third group, 130
- training, 148, 151, 153 ill., 179, 208-09, 210 ill., 214, 262-63, 264 ill., 265, 275, 290, 291 ill., 302, 321 ill., 322-25 ill.-26
- Atkinson, W. A., 487
- Atlas missile, 4, 59 ill., 69
- Atlas-Centaur launch vehicle, 206
- Atmosphere, spacecraft cabin, 157, 238
 - AS-204 pad and launch procedure, 230, 239
 - LM on launch pad, 240
 - oxygen, 157, 223, 230
 - oxygen-nitrogen, 222, 223, 230, 239-40
 - 60-40 mixture, 239-40
- Attitude control motors. *See* Reaction control motors.
- Atwood, Donald J., 487
- Atwood, J. Leland, 88, 195-96, 225, 230, 273, 488
- Augurson, Williams S., 11
- Aurora 7* (Mercury-Atlas 7), 114
- Avco Corp., 17, 42, 90, 94

- Babbitt, Donald O., 215, 217
- Back contamination. *See* Contamination.
- Backpack, astronaut. *See* Portable life support system.
- Bailey, D. K., 169
- Bailey, Glenn F., 17, 38
- Baird, L. E., 45
- Ballistic or blunt-body spacecraft, 26, 36 ill., 37
- Barlow, Edward J., 48
- Barlow, Mel R., 26, 488
- Baron, Thomas R., 222-23
- Baron report, 222-23
- Barr, William T., 488
- Bartley, William F., 217
- Barton, Richard E., 488
- Bassett, Charles A., II, 130, 207
 - death, 207, 217
 - Gemini IX*, 207
- Battersby, Frank X., 488
- Batthey, Robert V., 488
- Battin, Richard E., 39, 488
- Batteries, spacecraft, 9, 158, 342

- Bean, Alan L., 130, 262, 365
- Beaton, Roy H., 196
- Beauregard, Albert J., 488
- Becker, John V., 17
- Beech Aircraft Corp., 172
- Beeler, DeElroy E., 8
- Beggs, Cal, 488
- Belew, Leland F., 156
- Bell, David E., 25
- Bell, Leo R., 488
- Bell, Persa R., 333
- Bell Aerosystems Corp. (sub. Textron, Inc.), 17, 109, 113, 157
 - ascent engine, LM, 113, 154-55, 172, 200-01, 244-45
 - LLRV, 109-10
 - LLTV, 164
 - propellant tankage, spacecraft, 172
- Bellcomm, Inc., 120-21, 130, 152, 160, 364
- Bendix Corp., 202
- Benjamin, Warren, 488
- Benner, R. L., 488
- Bergaust, Eric, 219
- Bergen, William B., 224, 230-31, 238, 274, 488
- Berman, Kurt, 488
- Berry, Charles A., 220, 223, 230
- Berry, S. F., 52
- Beryllium shingles, spacecraft, 37
- Beta fiber. *See* Materials
- Bikle, Paul F., 110
- Bingman, Charles F., 97
- Biological isolation garment (BIG), 333, 355, 356 ill.
- Bird, John D., 67-69, 71, 488
- Bisplinghoff, Raymond L., 129
- Bixler, Charles, 488
- Blake, Dan, 488
- Bland, William M., Jr., 211
- Blasingame, B. P., 273
- Block I Apollo CM (earth orbital), xv, 87, 117, 133, 135, 138, 143, 229
 - cost, 229
 - CM-002, 190, 229
 - CM-004, 169
 - CM-007, 169
 - CM-009, 190-91, 229
 - CM-011, 229
 - CM-012, xv-xvi, 209-10 ill.-11, 213-16 ill., 220-22, 224-26, 229
 - CM-014, 209, 220
 - CM-017, 211, 231
 - CM-020, 247
 - difference from Block II, 137-38
 - electrical circuits, 172, 225-26
 - fire. *See* Apollo-Saturn 204.
 - Gemini spacesuits, 179
 - mockup review, 138, 139 ill., 140
 - reliability deficiency, 170

- slow development progress, 168-69, 171, 195-96, 229
- Block II Apollo CM (lunar orbital), xv, 117, 133, 135, 137, 140, 143, 149, 170-72, 175-76
- changes resulting from fire, 225-28
- Critical Design Review, 170-71
- CSM-101, 211, 224, 231, 238-40, 261
- definition work, 138, 140
- design or mockup reviews, 140-41, 162
- difference from Block I, 137-38
- docking system, 137 ill., 138, 140, 163, 288 ill.
- electrical circuits, 172
- EM³, 170
- first flight readiness, 202
- hatch. *See* Hatch, spacecraft.
- slow development progress, 168-69, 171, 195-96, 229, 237-38
- weight reduction, 138, 165
- Blount, Earl, 488
- Boardman, Warren, 156
- Bobik, Joseph M., 301
- Boeing Co., The, 17, 42, 51, 58, 100, 119, 334
- LRV, 365
- TIE contract, 228
- Bogart, Frank A., 329
- Boilerplate spacecraft. *See* Mockups and test vehicles.
- Bolender, Carroll H., 246, 257, 258, 299, 334
- Bond, Aleck C., 48, 239, 332
- Boost protective cover, CM, 134 ill., 142, 171, 217, 228
- Borman, Frank (*see also Apollo 8*), 116 ill., 262, 282, 283 ill.
- Apollo 204 Review Board, 219-21, 224
- AS-204 hearings, 224
- AS-205, 209, 261
- AS-503, 212
- CSM-101, 231, 263
- first manned lunar orbital mission, 258, 262, 274
- Gemini VII*, 182
- Bowman, Julian H., 258, 259
- Boynton, John H., 488
- Brader, Robert, 199
- Braking rocket, lunar descent, 75, 76, 81, 91
- Braley, E. C., 10
- Bramlet, James B., 57
- Brand, Vance D., 206, 262, 264, 275
- Brendle, Harmon L., 287
- Briggs, Glenn W., 488
- Briskman, Robert D., 45
- Brissenden, Roy F., 67
- Bromberg, Robert, 488
- Brooks, Overton, 25
- Broome, Douglas R., 214, 225
- Brown, B. Porter, 488
- Brown, Clinton E., 67, 69, 488
- Brown, Harrison, 125
- Bruning, William, 488
- Budget, NASA (*see also Appendix H*), 22-25, 29, 31, 35, 79, 110, 111, 167-68, 190 ill.
- FY 1960, 22
- FY 1961, 22
- FY 1962, 22, 23, 25, 58
- FY 1963, 110
- FY 1964, 110
- FY 1965, 167-68
- FY 1966, 167-68, 176, 202
- FY 1967, 189, 202
- FY 1970, 230
- supplemental, 110, 111, 127
- "Bug," lunar lander. *See* Lunar landing stage (vehicle, module).
- Buhler, Cary, 488
- Bull, John S., 206, 262
- Bunker, George M., 273
- Burke, Walter F., 273
- Bureau of the Budget, 25, 167, 168
- Burmood, R. O., 488
- Butler, Gordon, 488
- Buxton, Jack, 488
- Cabin, LM, 144, 146-48, 150 ill.
- atmosphere, 157, 238, 240
- cockpit size, 147
- controls, 148, 161
- elimination of seats, 149, 150 ill.
- exit and entry hatches, 145, 150-51, 153 ill., 161
- instrumentation and displays, 148, 149, 161
- lighting, 149, 161
- mockups, 150 ill., 161-62
- multiple uses, 147-48
- restraint system, 147
- tunnel, 150-51
- windows, 146-47, 149, 150 ill., 151, 153 ill., 161
- Cain, Darrell O., 215
- California Institute of Technology (*see also Jet Propulsion Laboratory*), 87, 102
- Call signs, spacecraft
- Aurora 7* (MA-7), 292
- Charlie Brown* (CM-106; *Apollo 10*), 302
- Columbia* (CM-107; *Apollo 11*), 331
- Eagle* (LM-5; *Apollo 11*), 331
- Faith 7* (MA-9), 292
- Freedom 7* (MR-3), 30
- Friendship 7* (MA-6), 114
- Gumdrop* (CM-104; *Apollo 9*), 292
- Liberty Bell 7* (MR-4), 292
- "Molly Brown" (*Gemini 3*), 292
- Snoopy*, (LM-4; *Apollo 10*), 302
- Spider* (LM-3; *Apollo 9*), 292

CHARIOTS FOR APOLLO

- "Titanic" (*Gemini 3*), 292
 Cameras, 248, 249, 266, 269, 278, 281, 297 ill., 298, 303, 310, 347, 348
 Canberra, Australia, 123
 Canards, CM, 133, 134 ill., 135, 141
 Canning, Frank X., 488
 Canning, Thomas N., 488
 Canright, Richard B., 45, 57
 Cape Canaveral (Kennedy), 50, 91, 114, 246 ill., 247
 Carbee, R. W., 162, 488
 Carley, Richard R., 17
 Carpenter, M. Scott, 30, 91 ill., 96, 114, 148, 207
 Carr, Gerald P., 206, 262, 275, 279, 281, 283 ill.
 Carroll, Robert E., 488
Carrying the Fire, 262, 277, 321
 Carter, David L. 48
 Cartoons, media, 218
 Case, Mel, 488
 Casey, Francis W., 488
 Cathers, H. B., 488
 Celestial mechanics, study of, 38, 39
 Centaur (upper-stage booster), 7, 9, 13
 Cernan, Eugene A. (*see also Apollo 10*), 130, 207, 261, 309 ill., 312 ill.
 AS-205, 212, 261
 Gemini IX-A, 207
 Certification of Flight Worthiness (definition), 169
 Chaffee, Roger B., 130, 210 ill.
 AS-204, 208, 209, 213, 214, 261
 death and burial, 217
 widow's court action, 224
 Chalmers, James F., 48
 Chamberlain Hotel, 42
 Chamberlin, James A., 42, 73, 75, 252, 323, 324, 488
 Chance Vought Aircraft, Inc., 14, 42, 67, 78
 Vought Astronautics, 14, 17, 66, 73
 Chapman, Dean R., 39
 Chapee, James H., 333
 Charlesworth, Clifford E., 248, 338, 488
Charlie Brown (CM-106), *See Apollo 10*
 "Charlie Frick's Road Show," 79-80
 Chauvin, Clarence A., 215
 Cheatham, Donald C., 488
 Checkout equipment, spacecraft. *See* Ground support equipment (GSE).
 Cherry, George W., 316, 317
 Chidley, D. W. 89
 Chilton, Robert G., 11, 14, 16, 17, 97, 488
 Chop, Albert M., 488
 Christensen, Everett E., 224
 Chrysler Corp., 51, 119, 191
 Church, James, 183
 Circumlunar flight, manned, 1
 early Apollo goal, xv, 6-7, 13, 15
 Goett Committee, 9-11
 Navy study, 112
 New Projects Panel, 11
 Piland study group, 12
 program possibilities, 20-21, 23, 25
 request for proposals, 15-16
 spacecraft design, 27, 37, 75, 117
 switch to lunar landing goal, 21, 23, 33, 34, 41, 46, 59
 Clagett, Albert A., 42
 Clark, J. R., 14, 66
 Clarke, E. E., 26, 28 ill., 488
 Clemence, Raymond R., 488
 Clements, Henry E., 488
 Clemmons, Steven B., 215, 217
 Clustered rocket engine concepts 5, 25, 45-47, 51, 54 ill., 56 ill., 57, 91, 183, 185
 Cohen, Aaron, 225, 488
 Cohn, Stanley H., 17
 Collins, Maurice W., 488
 Collins, Mathew R., 48, 49
 Collins, Michael (*see also Apollo 11*), 130, 262, 325 ill., 356 ill.
 Apollo 8, 276, 277
 Apollo 11 planning, 302, 318, 323, 325 ill.
 AS-205, 261
 AS-503, 212
 biological isolation garment, 333, 356 ill.
 Carrying the Fire, 262, 277, 321
 first man on the moon decision, 321
 Gemini X, 207, 294
 medical factors, 262, 276
 spacecraft naming, 331
 Collins Radio Co., 90, 159
Columbia (CM-107). *See Apollo 11*.
 Command module (CM), *Apollo*, xiv, 18 ill., 36 ill., 86 ill., 90 ill., 91 ill., 95 ill., 118 ill., 134 ill., 139 ill.
 "A to G" *Apollo* missions, 235
 BEF reentry and landing position, 133
 Block I. *See* Block I *Apollo* CM (earth orbital).
 Block II. *See* Block II *Apollo* CM (lunar orbital).
 boost protective cover, 134 ill., 142, 217, 228
 cabin atmosphere, 157, 222, 223, 230, 237, 238, 239-40
 canards, 133, 134 ill., 141
 CM-002, 190, 229
 CM-004, 169
 CM-007, 169
 CM-009, 190-91, 192 ill., 229
 CM-011, 229
 CM-012 (AS-204; *Apollo 1*), 209, 210 ill., 216 ill., 222, 229, 248
 Baron report, 223
 changes resulting from fire, 225, 226 ill., 228, 239-40

INDEX

- communications trouble, 214
- delivery, 209
- Design Certification Review, 211
- hatches, 214, 215, 217
- investigation, 220, 224
- problems, 209, 211, 214
- "There's a fire in here," 215
- CM-014, 209, 220
- CM-017 (AS-501; *Apollo 4*), *Apollo*, 211, 231, 232, 233 ill., 234
 - hatch and heatshield, 232
- CM-020 (AS-502; *Apollo 6*), 247-50
- CM-2TV-1 (thermal vacuum test model), 171, 264, 264 ill.
- CM-101 (AS-205; *Apollo 7*), 211, 257, 263, 265, 267
 - delivery, 253, 265
 - Design Certification Review, 240
 - factory testing, 263
 - first manned *Apollo* mission, 261, 266-71
 - flight readiness review, 265
 - manager, 224, 231
 - television, 266
 - windows, 268, 289
 - wiring, 238-39, 265
- CM-103 (AS-503; *Apollo 8*), 239, 276-84, 289
- CM-104 (AS-504; *Apollo 9*), 292-97 ill.-99
 - Gumdrop*, 292
 - mission switch, 262
 - wiring, 239
- CM-105, 239, 301
- CM-106, (AS-505; *Apollo 10*), 257, 258, 303-12
 - delivery, 301
 - Charlie Brown*, 302
 - flight readiness review, 301-02
 - wiring, 239
- CM-107 (AS-506; *Apollo 11*), 338-51 ill.-57
 - Columbia*, 331
- computer, 96, 97, 187
- configuration, 26-28 ill.-29, 35-36 ill.-38, 117-18 ill., 143-45 ill.-47, 168-70
- contract, 44, 132, 228-29
- contractor proposal conference, 42-43
- control thrusters. *See* Reaction control motors.
- costs, 132, 167-68, 178, 190 ill., 229
- definition and design, xv, 26, 27, 35, 37, 75, 121-22, 133
- development, 35, 37, 87, 89, 117, 131-32
- development contract. *See* Contracts, *Apollo*.
- docking function, 133, 137 ill., 138
- environmental control unit, 90, 157, 196, 209, 210, 214, 216 ill., 222, 223, 228, 229, 230, 239-40
- flammability studies and tests, 221, 222, 228, 237, 239
- flight test program, 91, 92, 93 ill. 190-91
- guidance system, 40 ill., 96, 97, 160
- heatshield. *See* Heatshield, ablative.
- inflight repair. *See* Inflight spacecraft repair.
- Little Joe II test concept, 91-93 ill.
- lower equipment bay, 170 ill., 171
- mission, 41, 75, 76, 86 ill.
- mockups and test vehicles. *See* Mockups and test vehicles, *Apollo*.
- parachutes, 94, 96 ill.
- probe and drogue docking device. *See* Docking, spacecraft.
- slow development progress, 91, 132, 133, 194, 195-96
- SM. *See* Service module, *Apollo*.
- source evaluation board. *See* *Apollo* CM Source Evaluation Board.
- stable I and II position in water, 263
- strakes, 133, 134 ill., 135
- structural tests, 89, 90 ill.
- subcontracts, 90
- subsystem delivery problems, 237-38
- tunnel. *See* Tunnel, spacecraft.
- weight, 138, 165, 170
- wind-tunnel work, 92, 94
- windows, 171
- Common-usage concept, spacecraft equipment, 108-09, 148, 157, 158
- Communications. *See* Tracking and communications network, worldwide.
- Computer, 39
 - Apollo 11* lunar landing, 343
 - CM, 96, 97, 187
 - Gemini spacecraft, 187
 - real-time computer complex, 185
- Configuration Control Board, 168, 173, 230, 239
 - first man on moon decision, 322
 - 1967 membership, 230
 - panels, 168, 172
- Configuration Management Plan, 168
- Congress, U.S., 3, 6, 13, 24, 25, 29, 35, 44, 52, 79, 110, 182, 185, 189, 357 ill.
- Apollo 8* joint session, 284
- Apollo 204* hearings, 219-25, 227
- House of Representatives, 29
 - Committee on Sciences and Astronautics, 25, 85, 219
 - Subcommittee on Manned Space Flight, 79
 - Subcommittee on NASA Oversight, 187, 201, 219, 223-24
 - Independent Offices Appropriations Committee, 53
 - Select Committee on Astronautics and Space Exploration, 6

CHARIOTS FOR APOLLO

- lunar receiving laboratory, 204
- NASA budget, 22-23, 25, 79, 110, 167-68, 177
- Senate, 24, 29
 - Committee on Aeronautical and Space Sciences, 219
 - Committee on Appropriations, 110
 - ten-year plan, 6
- Conlon, John W., 332
- Conrad, Charles, Jr., 116 ill., 148-49, 262, 277
 - Apollo 12*, 365
 - AS-503, 212, 261
 - Gemini V*, 182
 - Gemini XI*, 207, 294
 - LM flying qualities, 287
- Conrad, Paul, 218
- Contamination
 - from the moon (back), 185, 202, 204
 - of the moon and planets, 185
 - scientists worries before *Apollo 11*, 313, 333
- Contractor selection procedures, 42
- Contracts, Apollo (*see also* Appendix F), 15, 33, 35
 - CM, 35, 37, 38, 41-44, 67, 132-33, 178, 228-29
 - cost-plus-fixed-fee, 177
 - feasibility study, xiii, 15-17
 - guidance and navigation system, 38
 - incentive, 177-78, 229, 247
 - LM, 67, 113-14, 143, 177-78
- Control (definition of), spacecraft, 40
- Convair/Astronautics Div., General Dynamics Corp., 17, 19, 26-28 ill., 42-43, 78, 91, 93 ill., 100, 141
- Coons, D. Owen, 332
- Cooper, L. Gordon, 30, 182, 292, 302
- Cord, John N., 65
- Cornell University, 17
- Corning Glass Works, 226, 245
- Corps of Engineers, U.S. Army, 52, 53, 204
- Corrosion. *See* Stress corrosion.
- Cortright, Edgar M., 238
- Cosmonauts, xiii, xiv, 25, 29, 30, 115-16, 182, 227
- Cost of Apollo program, xiv, 20, 21, 22, 25, 27, 44, 105, 110, 114, 168, 190 ill., 229
 - Apollo 9* mission, 299
 - AS-204 accident, 230
 - CSM, 132, 178, 229
 - EMU, 296
 - FY 1969 experience, 286
 - LM, 109, 114, 146, 168, 177, 178, 197
 - per year expense, 167-68, 361-62
- Couches, 18 ill., 29, 36 ill.
 - CM, 137, 138, 139 ill., 140, 211
 - eliminated from LM, 149, 150 ill.
- Coursen, John, 199, 488
- Cozad, James C., 488
- Craig, Jerry W., 225
- Crawler-transporter, Saturn, 55 ill., 131 ill., 194-95, 196 ill.
- Crew complement, spacecraft, 12, 18 ill., 29, 105
- Crew Safety Review Board, 238, 240, 265
- Critical Design Review (definition), 169, 170
- Crossfield, A. Scott, 88
- Cryogenic propellant. *See* Propellant, launch vehicle.
- Cuban missile crisis, 107
- Cumberland Island, 50
- Cunningham, R. Walter (*see also* *Apollo 7*), 130, 139 ill., 261, 264 ill., 271 ill.
 - AS-205, 209, 261
- Cuzzopoli, Joe, 488
- Dandridge, Manning, 156, 488
- Daniels, E. J., 65
- Daniels, James L., Jr., 329
- David Clark Co., 179
- David, Dan, 193
- Davis, Hubert P., 488
- Davis, Leighton I., 50, 131 ill.
- Deans, Philip M., 488
- Deaths
 - astronaut, xvi, 207, 217, 262
 - at Brooks Air Force Base, 217
 - cosmonaut, 227
 - NASA Deputy Administrator, 182
 - President, 131
- Debus, Kurt H., 55 ill., 128-29, 131 ill., 192, 211, 308 ill.
 - lunar orbit mission proposal, 257-58
 - management council, 129
 - Saturn launch safety, 241
 - space launch facilities, 50-51
- Debus-Davis study, 50
- Decker, James L., 160
- Decrevel, Ron, 488
- DeFries, Paul J., 45
- Demarest, David, 488
- Dembling, Paul G., 52, 329, 488
- De Moraes, Carlos, 26, 28 ill.
- De Nike, John, 488
- Department of Agriculture, 204
- Department of Defense, 9, 30, 46, 49
- Der Bing, William, 488
- Descent engine, LM, 109, 145 ill., 154-55, 162 ill.
 - Apollo 5*, 242
 - Apollo 9*, 295, 298
 - Apollo 10*, 310
 - Apollo 11*, 343
 - backup chore, 144
 - competitive contractors, 113, 154, 155-56

- description, 155, 200
- development, 154, 156, 200
- gimbaled (able to swivel), 155
- hypergolic fuel system, 155
- pacing system, 187
- Subcontractor Review Board, 156
- Descent orbit insertion (DOI), toward lunar surface
 - Apollo 10*, 310
 - Apollo 11*, 343
- Descent stage, LM, 144, 145 ill., 243 ill., 299
 - design, 144, 146
 - lunar surface launch pad, 144, 146, 352
 - lunar orbit abort, 146, 242
 - LRV, 364
 - MESA, 321 ill., 323, 341
- Descent stage, lunar landing vehicle, 62
- Descent trajectory analysis, lunar, 69, 109, 316-17
- Design, spacecraft, 18, 26, 27, 35, 37, 136
 - CM. *See* Command module (CM), *Apollo*.
 - Convair/Astronautics proposal, 27, 28 ill.
 - General Electric proposal, 27, 28 ill.
 - LM. *See* Lunar module (LM), *Apollo*.
 - Martin Co. proposal, 27, 28 ill., 29
- Design Certification Review (definition), 169
- Design Reference Mission, 136-37
 - Apollo Mission Planning Task Force, 163
- Desjardin, Lee, 488
- Dessler, Alex J., 488
- Direct ascent (lunar flight mode proposal), 44, 51, 59, 61, 63 ill., 77, 82-84, 117
 - backup for EOR, 59, 79
 - estimated cost, 83
 - avored by Air Force, 62
 - avored by Fleming Committee, 34
 - avored by Piland (STG) study group, 12
 - avored by NASA Headquarters, 31
 - final rejected by STG (later MSC), 75-76
 - Golovin Committee study, 48-49
 - Low Committee study, 23
 - lunar landing problems, 61, 75, 76
 - opposed by Langley group, 67, 68, 69, 72
 - opposed by von Braun group, 9, 21, 62, 63
 - propulsion requirements for, 9, 45
 - Rosen Committee study, 57, 58
 - study of other options, 8, 46, 79, 80
 - two-man proposal, 80, 84-85, 103-06
- Disher, John H., 9, 15, 17, 37, 57, 130, 136, 176, 488
- Ditke, Robert R., 488
- Docking, spacecraft, 27, 58, 61, 62, 72, 80, 86
 - ill., 99, 101, 108, 117, 132 ill., 133, 137 ill., 144, 145 ill., 163, 288 ill.
 - Apollo 9*, 287, 290, 293, 297 ill., 299
 - Apollo 10*, 303, 307, 311
 - Apollo 11*, 339, 353
 - Gemini VIII*, 205
 - probe and drogue, 137 ill., 140, 163, 287, 288 ill., 293, 306, 340, 342, 353
 - procedures, 137, 150-51
- DoD-NASA Large Launch Vehicle Planning Group. *See* Golovin Committee
- Dodge, Harold E., 488
- Dodgen, John A., 67
- Dolan, Thomas E., 14, 66, 73, 488
- Donlan, Charles J., 14, 15, 17, 19, 21, 26, 488
- Doolittle, James H., 4
- Dornbach, John E., 185
- Douglas Aircraft Co., 17, 35, 42, 83, 100, 112
 - Saturn S-IVB stage contract, 58, 191
- Douglas, Paul H., 65
- Dow-Corning Corp., 94
- Downhower, Walter J., 34
- Drake, Hubert M., 45
- Draper, C. Stark, 39, 40 ill., 41, 273, 488
- Drogue and probe docking device. *See* Docking, spacecraft.
- Dryden, Hugh L., 3, 6, 8, 22, 33, 56, 117, 129, 182, 488
 - announces *Apollo*, 15
 - Apollo* mode issue, 30, 46, 79, 84, 85, 106
 - choice of CM contractor, 44
 - death, 182
 - Deputy NASA Administrator, 3, 24
 - insulating research from operation centers, 4
 - lunar guidance and navigation, 41
 - relations with scientific community, 365
 - selecting manned space laboratory site, 52
 - space program costs, 127, 362
 - space program funding, 30, 31
- DuBridge, Lee A., 365
- Duff, Brian M., 327, 328
- Duggan, Orton L., 488
- Duke, Charles M., Jr., 206, 252, 263, 340, 345
- Duncan, Robert C., 174, 183, 199, 200
- Dust, lunar, 99, 109
 - Apollo 11*, 344, 346, 347, 349, 350-51 ill., 353
 - LM design worries, 152
 - Surveyor I* pictures, 206
- Eagle* (LM-5; *Apollo 11*), 331
- Early *Apollo* Scientific Experiments Package (EASEP), 320
- Earth-landing sites proposed, *Apollo*, 27, 135
- Earth landing systems, proposed, 94
 - flexible wing (paraglider), 94, 96
 - parachutes. *See* Parachutes, spacecraft.
 - rotating wing, 94
- Earth orbital flights. *See* Orbital flight, manned earth.
- Earth orbital operations, 9, 23, 67, 72, 73-75, 110, 117, 132
- Earth-orbit rendezvous (lunar flight mode proposal), 51, 59, 63 ill., 69, 85

CHARIOTS FOR APOLLO

- compared with direct ascent, 9, 83, 84, 105
- compared with LOR, 72, 79, 83, 105
- disadvantages, 9, 72
- estimated cost, 83
- avored by Ames group, 80
- avored by Heaton Committee, 45, 70
- avored by Lundin Committee, 34, 45
- avored by NASA Headquarters at end of 1961, 59, 79, 85
- avored by von Braun group, 6, 21, 62, 63, 66, 77, 80, 81, 82
- Fleming Committee study, 34
- Golovin Committee study, 48, 71
- Holmes-Shea studies, 77, 78
- Low Committee study, 23
- PSAC interest, 101, 102, 103, 106, 107
- Rosen Committee study, 57, 58
- von Braun switch, 82
- Edwards, J. J., 488
- Edwards Air Force Base, Calif., 109
- Eggers, Alfred J., Jr., 8, 27, 34, 35, 80, 488
- Eggleston, John M., 67, 73, 363, 488
- Eglin Air Force Base, Fla., 91
- Ehrlicke, Kraft A., 488
- Eickmeier, Alfred B., 122
- Eisele, Donn F. (*see also Apollo 7*), 130, 139 ill., 148, 209, 261, 264 ill., 271 ill.
 - AS-205, 209, 261
- Eisenhower, Dwight D., 7, 13, 14
- Electrical system, spacecraft, 9, 238
 - CM, 221-22, 225, 238
 - LM, 108-09, 158, 171-72, 176
- Ellington Air Force Base, Tex., 108
- ELM (extended lunar module), 362, 363, 364
- Elms, James C., 93 ill., 129
- Elverum, Gerard W., Jr., 488
- EM³ (engineering manufacturing module mockup), 170
- Emme, Eugene M., xvii
- EMU. *See* Extravehicular mobility unit.
- Engle, Joe H., 206, 264 ill., 302
- Environment, spacecraft, 16
 - launch pad test, 214, 230, 239
 - one- versus two-gas system, 222, 223, 239-40
 - pad and launch procedure, 230, 240
 - "shirt sleeve," 16, 96
 - two-gas system, 222, 223, 230, 239-40
- Environmental control unit, spacecraft
 - CM, 90, 157, 196, 209, 214, 216 ill., 222, 223, 225, 228, 229, 230
 - dangers of two-gas system, 239-40
 - LM, 154, 157, 176, 240
- Erb, R. Bryan, 333
- Ertel, Ivan D., xvi
- Escape system. *See* Launch escape system.
- Escher, William J. D., 34
- Evans, B. O., 273
- Evans, Brian, 198, 488
- Evans, Llewellyn J., 197, 198, 199, 299
- Evans, Ronald E., 206, 262, 318
- Ewing, Edgar G., 488
- Exer-Genie, 269
- Experiments, lunar science, 125-26, 202, 260-61
 - ALSEP, 202, 319, 363
 - EASEP, 320
 - piggyback role in Apollo, 229, 320, 363
- Experiments, space flight (*see also* Appendix D)
 - ALSEP, 202, 319, 363
 - Apollo 7*, 266
 - Apollo 9*, 291
 - Apollo 11*, 313, 321 ill., 348, 351 ill.
 - AS-204, 209
 - AS-205, 209, 211
 - EASEP, 320
 - Gemini program, 208
- Experiments Program Office, 202
- Explorer (satellite and space probe program), 4
- Extended lunar module (ELM), 362-64
- Extravehicular activity (EVA), astronaut, 137, 150-51, 153 ill., 269, 364
 - Apollo 9*, 290-91, 295-96, 297 ill., 298
 - Apollo 11*, 319-21, 321 ill., 322, 323, 324, 325 ill. 345-49, 350-51 ill.
- Gemini program, 182, 207, 208, 268-69
- lunar surface walks. *See* Walks, lunar surface.
- post-*Apollo 11* plans, 364
- Extravehicular mobility unit (EMU), 178, 296, 297 ill., 321 ill., 323, 324, 345, 346, 349, 350-51 ill.
- Ezell, William F., 488
- F-1 rocket engine, launch vehicle, 118, 184 ill.
 - clustered, 25, 46, 51, 183
 - combustion instability, 122
 - first successful clustered engine firing (static test), 183
 - funds for, 25, 45
 - Golovin Committee study, 49
 - key to manned lunar landing, 25
 - launch vehicle stage descriptions, 47
 - NASA-sponsored development, 6
 - pogo problem, 248, 250, 251, 252, 303
 - Rosen Committee study, 58
 - transferred from Air Force, 4
- Faber, Stanley, 488
- Facilities, Apollo program, 46, 50, 51, 53, 54 ill., 55 ill.
 - construction, 53
 - land acquisition, 50, 51, 53

- launch, xv, 50, 51, 56 ill., 104, 118
 launch vehicle development and assembly,
 50, 51, 54 ill.
 launch vehicle test, 50, 51, 54 ill.
 location, 50, 51, 52, 53
 Faget, Maxime A., 16 ill., 488
 Apollo CM design, 35, 37, 140
 Apollo 11 photographic plans, 329
 Apollo 204 Review Board, 219, 220
 Apollo launch vehicle study, 45
 Apollo mission sequence, 62, 75, 76
 Apollo mode issue, 62, 75, 76, 79
 CM special tests, 225, 239, 240
 CM weight, 170
 committee work, 8, 14, 23
 feasibility studies, 17, 21, 26
 LM design, 99, 162
 LM propulsion, 156, 201, 302, 334
 NASA-industry conference, 16
 paraglider opponent, 94
 Source Evaluation Board, 42
 spacecraft configuration control, 230
 spacecraft docking concerns, 287
 subsystem managers, 135
 Fairchild Stratos Co., 180-81
Faith 7 (MA-9), 292
 Falbaum, Sanford, 488
 Feasibility studies and contracts, Apollo, 15-
 19, 21, 26, 27, 35, 38, 39, 41, 42, 66, 112
 bidders, 17, 19
 contract awards, 17
 costs, 27, 29
 evaluation of proposals, 17, 26, 29
 guidelines, 16
 submissions, 27, 28, 28 ill., 29
 Feld, David, 488
 Feltz, Charles H., 88, 88 ill., 89, 138, 488
 Feldman, Saul, 488
 Ferguson, Richard B., 17
 Fichtner, Hans J., 122
 Field, Robert E., 193, 488
 Finkelstein, Nissan A., 488
 Fire
 AS-204, xv, 215, 216 ill., 217, 220-25, 230,
 239, 261
 hazard, 221-25, 230, 238
 prevention, 221-24, 239
 simulation chamber, 217
 S-II stage test, 194
 Fire extinguishers, spacecraft, 222
 First manned landing on moon, 343-44
 First words from moon
 in spacecraft, 344
 from surface, 346
 Fisher, Lewis R., 488
 Fitzgerald, Charles, 488
 Flag, 314, 329, 330, 347
 Flagg, Henry W., Jr., 488
 Flammability studies and tests, spacecraft,
 221, 222, 228
 Senior Flammability Board, 238, 239
 Fleming, William A., 34, 45, 46, 65
 Fleming Committee, 34, 45
 Flight Article Configuration Inspection
 (definition), 169
 Flight directors, Apollo mission, 190, 267, 292,
 303, 338
 Flight Readiness Review (definition), 169
 Flight Research Center, NASA (*see also* High
 Speed Flight Station), 94, 109
 FTA (flight test article), LM, 176
 Flight test program (*see also* Little Joe II
 launch vehicle)
 "all-up" decision, 130
 boilerplate CSMs, 91-93 ill.
 LM, 175-76
 Food, space flight, 269, 305
 Forest, Casey, 488
 Frangible probes, LM landing gear, 172, 173
 ill., 344
 Franklin, George C., 149
 Frasier, Cline W., 173
 Freedman, Toby, 488
Freedom 7 (MR-3), 30
 Freeman, Theodore C., 130
 death, 207, 217
 Freitag, Robert F., 129
 Frick, Charles W., 488
 Apollo CSM contract, 132
 "Charlie Frick's Road Show," 79-80
 first Apollo spacecraft manager, 78, 98
 leaves NASA, 133
 LM design work, 99, 100
Friendship 7 (MA-6), 114
 Frutkin, Arnold W., 329, 330
 Fuel cell (generator of electrical energy), 9,
 158, 171, 268
 Fuels, rocket. *See* Propellant.
 Fulton, James G., 230
 Funk, Jack, 11, 17, 488
 Funding. *See* Cost of Apollo program and
 Appendix H).
 Gagarin, Yuri A., xiii, 25, 29, 30
 Gainesville, Miss., 52
 Galman, Barry, 489
 Garriott, Owen K., 180, 349
 Garrison, Arthur E., 97
 Gates, Sally D., xvi
 Gavin, Joseph G., Jr., 115 ill., 489
 Grumman Apollo proposals, 112, 113
 LM contract, 113
 LM development organization, 198, 199
 LM propulsion, 156, 245
 lunar orbit mission proposal, 274

CHARIOTS FOR APOLLO

- Geer, E. Barton, 219, 220, 332
 Gemini. *See* Project Gemini.
 Gemini spacecraft, 73-75, 92, 94, 104-106, 108, 115, 118 ill., 180
Gemini III ("Molly Brown"), 181-82, 292
Gemini IV, 182, 186
Gemini V, 182
Gemini VI-A, 182, 205, 266
 influence on *Apollo 9*, 290
 world's first space rendezvous, 182
Gemini VII, 182, 205, 276, 290
Gemini VIII, 205, 207
 first vehicular docking in space, 205
Gemini IX-A, 207, 267
Gemini X, 207, 294
Gemini XI, 207, 294
Gemini XII, 208
 General Accounting Office LM investigation, 158
 General Dynamics Corp., Convair/Astronautics Div., 17, 19, 26-28 ill., 42-43, 78, 91, 93 ill., 100, 141
 General Electric Co., 17, 88, 121
 Apollo feasibility study, 17, 19, 26-28 ill.
 Apollo integration contract, 119, 122
 bid on Apollo CM contract, 42-43
 space vehicle GSE role, 119-20 ill., 196, 199, 228
 Geological Survey, U.S., 39
 Gibson, Cecil R., 244
 Gibson, Edward G., 180
 Gilbert, David W., 160, 489
 Gilbert, Porter H., 489
 Gilruth, Robert R., 3 ill., 16 ill., 282 ill., 489
 "all-up" decision, 130
 Apollo 8, 285
 Apollo CM contract, 35, 37, 43, 44
 Apollo CM design, 37-38, 165
 Apollo feasibility contracts, 17-18
 Apollo flight mode issue, 48, 65, 69, 70, 75-77, 79, 81
 Apollo flight program, 130, 189, 285
 Apollo follow-on program, 188
 Apollo guidance system, 97
 Apollo launch vehicle question, 46, 48, 57
 Apollo lunar site selection, 185
 AS-204 Design Certification Review, 211
 AS-204 recovery, 225, 231
 astronaut corps, 180, 206
 autonomous field activity, 18, 50
 director of MSC, 56, 98, 107
 director of STG, 4
 impression of Apollo task, 31
 incentive contracting, 177
 LEO, 182
 LLTV, 323
 LM contract, 114, 177
 LM design, 99, 100, 165
 LM flying qualities, 287
 LM ground testing, 163
 LM program review, 197
 LM propulsion, 156
 LM stress corrosion, 245
 location of manned space flight activity, 18-19, 22, 50, 52-53, 115
 Lunar Exploration Working Group, 363
 lunar orbit mission proposal, 257, 259, 260
 Lunar Receiving Laboratory, 204-05, 332, 333
 lunar surface walks, 320, 324
 management council member, 58, 129
 Mission Control Center, 115
 NASA-industry conference, 15
 New Projects Panel, 11
 Piland study group, 14
 pre-*Apollo 11* worries, 334
 public affairs and *Apollo 11*, 326, 327, 328
 relations with NASA Headquarters and other centers, 4, 18, 21, 97, 128, 286
 science and Apollo, 125, 202, 362-63
 Senior Flammability Board, 238, 239, 240
 spacesuits, 179
 STG organization and mission, 12, 21, 22
 symbols for *Apollo 11*, 329
 upgrading Apollo capabilities, 362
 Givens, Edward G., Jr., 206
 Glasser, Otto J., 48
 Glassman, L. H., 45
 Gleaves, James D., 215, 217
 Glenn, John H., 30, 91 ill., 96, 114, 272
 Glennan, T. Keith, 3 ill., 489
 Apollo flight mode, 62
 beginnings of Apollo program, 14, 15, 20, 22, 24
 contracting procedures, 42
 framing a national space program, 4-8, 11, 13-14
 launch vehicle development, 3, 6, 13-14
 leaves NASA, 22, 24
 manned space flight activity location, 18-19, 22
 NASA Administrator, first, 3
 NASA-industry conference, 15
 organizing NASA, 3-4
 Goddard, James L., 204
 Goddard, Robert H., 4
 Goddard Space Flight Center, NASA, 4, 18, 39
 real-time computer complex, 185
 tracking network responsibilities, 115, 123
 Goett, Harry J., 4, 7-11, 13, 17, 18, 20, 489
 Goett Committee, 7-11, 13
 Gold, Thomas, 348
 Goldstone, Calif., 123, 206, 328
 Goldstone, N. J., 489

INDEX

- Golovin, Nicholas E.
 Apollo CM reliability, 170
 Apollo flight mode issue, 48-49, 70-71
 Apollo launch vehicle study, 48-49, 70
 PSAC against Apollo flight mode, 84, 100-04, 106-07
- Golovin Committee, 48-49, 57, 70-71, 73, 102
- Goodrich, B. F., Co., 179
- Goodyear Aircraft, 17, 42
- Goodwin, Glen, 489
- Gordon, Richard F., Jr., 130, 208, 262, 277
Apollo 12, 365
 AS-503, 212, 261
Gemini XI, 207, 294
- Gorce, Jesse F., 489
- Goss, J. R., 489
- Gough, Melvin N., 489
- Graham, H. B., 183
- Grant, Arthur F., Jr., 489
- Graveline, Duane E., 180
- Gravitational field, earth's, 23, 231, 274-75, 278
- Gravity, lunar, 14, 109, 300, 340
 Aldrin and Armstrong, 345, 346, 347
Apollo 11 concerns, 316-18
 astronaut walking concerns, 313
 simulations, 109, 151, 324, 325 ill.
- Gray, Wilbur H., 489
- Green, Don J., 489
- Greer, Robert E., 194, 195
- Griffin, Gerald D., 267, 270 ill.
- Griffith Planetarium, 263
- Grimm, Dean F., 489
- Grissom, Virgil I., 30, 210 ill., 261, 292
Apollo 1, 210 ill., 231
 AS-204, 208-10 ill.-17, 241, 261
 burial, 217
 CM-012 complaints, 214
 death, 216 ill., 217, 230
Gemini 3 ("Molly Brown"), 181, 292
 MR-4 (*Liberty Bell 7*), 292
 Mercury spacecraft hatch, 215
 space program quotes, 220
 widow's court action, 224
- Gross, Alexander, 489
- Ground support equipment (GSE)
 General Electric, 119-20
 LM, 165, 176, 198-99
 pacing item, 187, 198
- Grumman, Leroy R., 111
- Grumman Aircraft Engineering Corp., 17, 42, 83, 100, 108, 111-14, 127, 135-36
 budget problems, LM, 197
 Design Reference Mission, 136-37
 facilities, 108, 113, 114, 165
 GSE problems, 165, 198-99
 Kelly, Gavin study groups, 111-13
- LM design, 108, 113, 137, 143-44 ill.-45 ill.-62
- LM development contract, 108, 111, 113-114, 143
- manufacturing problems, 147, 175, 256
- NASA review team, 197-98
- relationships with MIT and NAA, 160-61, 163
- subcontract supervision, 113-14, 198
- test articles and program, 108, 113, 163-65
- Guardite, 17
- Guidance (definition), 40
- Guidance, control, and navigation, xv, 16-18, 26, 38-40 ill.-41, 196-97
- CM, 38-40 ill.-41, 86, 96-97, 172
Apollo 7, 268
Apollo 8, 276-77, 278-79, 281-82
 computer. *See* Computers.
 contract, 38-39
 gyroscope 38, 96, 196-97
 industrial contractors-MIT relations, 97-98
 inertial measurement unit, 96-97
 MIT development role, 40, 97-98
 NAA-MIT relations, 96
 operation, 96-97
 reentry. *See* Reentry, spacecraft.
 sextant, 96-97
- LM, 73, 99, 108, 160
Apollo 10, 309 ill., 310-11
Apollo 11, 316-18 343-44, 352-53
 attitude reference ("eight ball"), 148
 computer, 109
 Grumman-MIT relations, 160, 163
 inertial measurement unit, 108
 radar linkage, 159
 selection controversy, 160
 stabilization and control system linkage, 158-59
 telescope, 108
- Gumdrop* (CM-104; *Apollo 9*), 292
- Gwinn, William P., 274
- Gyroscope, 38, 96, 196-97
- "H" missions, Apollo, 364
- H-1 rocket engine, launch vehicle, 47, 190, 191
- Hage, George H., 251, 257, 259, 260, 261
- Hahn, Jack R., 489
- Haines, Richard F., 489
- Haise, Fred W., Jr., 206, 262, 318
- Hall, Albert C., 489
- Hall, Eldon W., 13, 21, 23, 48, 57, 65
- Hall, Harvey, 48
- Hamilton Standard (div. of United Aircraft Corp.)
 Apollo spacesuit, 178 ill.-79

CHARIOTS FOR APOLLO

- LM environmental system, 154, 157, 176
- portable life support system (backpack), 178-79
- relations with International Latex Corp., 178-79
- Hammack, Jerome B., 283, 489
- Hammersmith, John L., 45
- Hammes, Ted, 489
- Hammock, David M., 57
- Haney, Paul P., 266, 279, 326, 327, 329
- Hardy, Gordon H., 489
- Harmon, Richard G., 217
- Harter, Alan C., 217
- Hartung, Jack B., 489
- Hatch, spacecraft
 - CM, 96, 137 ill., 140, 215, 221, 225, 226 ill., 228, 229, 232
 - CM-012, 214, 215, 217
 - CM-020, 247
 - explosive and mechanical, 96, 215
 - LM, 144, 150-51, 153 ill., 226
- Hauenstein, Clifford A., 489
- Hawaii, 50, 276
- Hawkins, Jerry W., 215, 217
- Hazard, Allyn B., 64
- Healey, John P., 224, 231, 489
- Heating, spacecraft reentry. *See* Reentry heat protection.
- Heaton, Donald H., 45
- Heaton Committee, 45, 70-71
- Heatshield, ablative, 9, 29
 - Apollo CM, 35, 37, 89, 90, 94, 95 ill., 133, 134 ill., 138, 139 ill., 181
 - AS-201, 192 ill., 193
 - AS-202, 194
 - AS-501 (*Apollo 4*), 232, 233-34
- Heeb, Malcolm H., 19
- Heberlig, Jack C., 37, 489
- Hello, Bastian, 224, 489
- Henderson, Melba S., xvi
- Henry, Richard C., 97
- Hess, Harry H., 180
- Hess, Wilmot N., 230, 320, 324, 363, 489
- High Speed Flight Station, NASA (*see also* Flight Research Center, NASA), 8, 19
- Highsmith, Helen, 489
- Himmel, Seymour C., 48
- Hjornevik, Wesley L., 3, 19, 42, 46, 197, 198, 199, 247
- Hoag, David G., 39, 40 ill., 489
- Hoberg, Otto A., 122
- Hobokan, Andrew, 489
- Hodge, John D., 12, 122, 190, 205, 489
 - Apollo Crew Safety Review Board, 240, 241, 265
 - extended LM (ELM), 363
 - LRL readiness, 332
 - lunar exploration working group, 363
- Hoelker, Rudolf F., 122
- Hoffman, Arnold I., 489
- Hoffman, Samuel K., 88, 489
- Holden, George R., 489
- Holland, Howard, 489
- Holmburg, Mervin, 223
- Holmes, D. Brainerd, 55 ill., 56, 86 ill., 96, 489
 - Apollo and Gemini budgets, 110, 128-29
 - Apollo flight mode, 59, 76-81, 83-85
 - defense, 85-86, 102, 106, 108
 - Bellcomm and GE contracts, 119, 120
 - launch vehicle study and decision, 57-59
 - leaves NASA, 128
 - LM contract, 108
 - management council, 58-59, 78, 129
 - OMSF buildup, 121
 - Panel Review Board, 122
- Holmes, Jay, 489
- Honeywell, 90, 158, 172
- Hornby, Harold, 80, 489
- Horner, Richard E., 18
- Hornig, Donald F., 19
- Houbolt, John C., 15, 45, 67-73, 78-79, 82, 489
- Hound Dog missile, 43, 89, 133, 140
- Houston, Tex., 53, 115
- Hubner, R. W., 273
- Hudson, Lincoln, 489
- Hughes Aircraft, 42, 200
- Hughey, B. J., 489
- Human factors, space flight, 17, 26, 92, 139 ill., 148, 150 ill., 161
- Hunter, Robert B., 274
- Hurt, Jack B., 93 ill., 141, 489
- Huss, Carl R., 276, 300, 318, 489
- Huston, Vincent G., 274
- Huzel, Dieter K., 489
- Hyatt, Abraham, 13, 25, 46, 64, 65
- Hyland, Lawrence A., 19
- Hydrogen, liquid. *See* Propellant.
- Hypergolic propellant. *See* Propellant.
- IBM (International Business Machines Corp.
 - Mission Control and spacecraft computers, 186-87
 - Saturn instrument unit, 191, 273
- Incentive contracts. *See* Contracts, Apollo.
- Inflight spacecraft repair, 135, 140, 159
 - canceled, 140, 159, 171
 - CM, 135, 140, 159, 171
 - LM, 159
- Instrument unit, Saturn, 191, 273
- Instrumentation, spacecraft pilot control, 40 ill., 91 ill., 92, 161, 162
- Intercontinental ballistic missiles, 1, 39
- Interagency Committee on Back Contami-

- nation, 333
- Interface (module, vehicle, component, system), 82, 163
- Interface control documents, 98, 123, 160-61
 - definition and application, 98
- Integration (space vehicle or system), 18, 76, 128
 - Boeing "TIE" contract, 228
 - General Electric role, 119, 122
- International Latex Corp., 178
 - relations with Hamilton Standard, 178-79
 - spacesuit contract, 179
- Intravehicular activity, astronaut (comments during *Apollo 7*), 269
- Irwin, James B., 206, 302
- ITT (International Telephone & Telegraph Corp.), 17
- Interplanetary exploration, unmanned, 13
- Interplanetary travel, manned (proposed), 8, 63, 188, 362
- Intransit rendezvous (proposed lunar flight mode), 65
- "J" missions, Apollo, 364
- J-2 rocket engine (in Saturn S-II and S-IVB stages), 47, 49, 58, 118, 191, 194, 195 ill., 248, 252
- Jacks, Verne L., xvi
- Jackson, Karl F., 489
- James, Lee B., 211, 251, 252, 257, 259, 273, 274
- Jarvis, Calvin R., 489
- Jeffs, George W., 219, 489
- Jenkins, Lyle M., 122
- Jenkins, Thomas E., 329
- Jet Propulsion Laboratory (NASA contractor), 3, 8
 - Apollo flight mode, 48, 64
 - lunar experiments program, 202
 - Ranger program, 181
 - Surveyor program, 206
 - tracking and communications, 123-24
- Johansen, John H., 489
- Johnson, Caldwell C., Jr., 489
 - Apollo flight mode, 76
 - CM design, 11, 18, 18 ill., 26, 37, 97, 138, 169-70
 - LM weight problem, 174
 - New Projects Panel, 12
 - spacecraft control thrusters, 157
- Johnson, George W. S., 34
- Johnson, Harold I., 17
- Johnson, Irving A., 156
- Johnson, Lyndon B.
 - Apollo 8*, 284
 - did not seek reelection, 250
 - Gemini V* and Apollo mission, 182
 - location of manned space flight center, 53
 - NASA budget, 189
 - selecting NASA administrator, 24
 - selecting NASA deputy administrator, 258
 - space race, 29
 - space treaty, 218
- Johnson, W. Kemble, 489
- Johnston, Richard S.
 - Apollo feasibility studies, 16-17
 - AS-204 accident, 220
 - back contamination, 333
 - LRL readiness, 332
 - lunar surface operations, 326
 - symbols for *Apollo 11*, 329
- Johnston, Robert L., 225
- Jones, David M., 188, 241
- Juno V launch vehicle, 5-7, 62
- Jupiter missile, 35
- Kapp, Michael, 271
- Kapryan, Walter J., 265, 308 ill., 489
- Karegeannes, Carrie E., xvii
- Kavanau, Lawrence L., 48, 49, 489
- KC-135 aircraft, 324
- Kehlet, Alan B., 489
 - Apollo feasibility studies, 17
 - CM Block II design, 140, 170, 171
 - Little Joe II, 91
 - New Projects Panel, 11
- Kelly, G. Fred, 217
- Kelly, Thomas J., 489
 - AS-204 aftermath, 225
 - elimination of LM seats, 149
 - LM design contract, 113, 144
 - LM mockup review board, 162
 - LM weight reduction, 174
 - space study work, 112, 144
- Kemmerer, Walter W., Jr., 333
- Kennedy, John F., 22, 46, 110
 - Apollo flight mode, 102-04, 107
 - assassination, 51, 131
 - Cuban missile crisis, 107
 - lunar landing challenge, xiii, xvi, 29-33, 62, 104, 125, 284, 285, 313
 - NASA uncertainties, 22, 23
- Kennedy Space Center, John F., NASA, 51, 231, 232, 288
 - launch complex locations, 246 ill., 247
 - Merritt Island Launch Annex, 232
 - previous designation. *See* Launch Operations Center, NASA.
- Kerwin, Joseph P., 180, 264 ill., 332, 333
- Kiker, John W., 94
- Kimpton, Lawrence A., 24
- Kimpton Report, 24
- King, Alan, 489
- King, Charles H., 156
- King, Elbert A., Jr., 489
- King, Martin Luther, Jr., 250

CHARIOTS FOR APOLLO

- Kingfield, Joseph P., 489
 Kingsley, Milton, 122
 Kistiakowsky, George B., 19
 Kleinknecht, Kenneth S., 42, 116, 230, 247, 258, 287, 489
 Klemas, Vytautas, 489
 Knacke, Theodore W., 489
 Knauf, George M., 129
 Koelle, Heinz H., 5, 17, 23, 45
 Kollsman Instrument Corp., 97, 160
 Komarov, Vladimir M., 227
 Koppenhaver, James T., 42, 97
 Kotanchik, Joseph N., 211, 245, 258, 287
 Kraft, Christopher C., Jr., 282 ill., 489
 Apollo 8, 276
 Apollo mission planning, 189, 190, 205, 231, 314
 CM mockup review board, 138
 inflight spacecraft repair, 159
 LM mockup review board, 162
 lunar orbit mission proposal, 256-59, 273-74
 Mission Control Center, 114-15, 186
 recovery plans for *Apollo 11*, 333
 spacecraft configuration control, 230
 spacecraft docking concerns, 287
 stretching Apollo landing zone, 363
 Kranz, Eugene F., 242, 267, 270 ill., 292
 Kroupa, Charles E., 489
 Kuettner, Joachim P., 122
 Kupczyk, Richard R., 489
 Kupfer, Walker, 489
 Kurbjun, Max C., 67, 68
 Kyle, Howard C., 17
- Laboratory, proposed manned space, 8, 9, 10, 12, 13, 16, 23, 25, 41, 67, 188
 Lambert, C. Harold, Jr., 156
 Landing, spacecraft, discussion of water and ground, 16, 89, 94, 96, 135
 Landing and recovery, spacecraft, 16, 94, 96, 135, 263
 Apollo 4, 233
 Apollo 6, 249
 Apollo 7, 271, 271 ill.
 Apollo 8, 283, 284
 Apollo 9, 299
 Apollo 10, 312
 Apollo 11, 355-56 ill.-59
 AS-201, 193
 AS-202, 194
 Landing gear. *See* Legs (gear), lunar landing vehicle.
 Lang, Dave W., 42, 156, 489
 Lange, Oswald H., 42
 Langley Research Center, NASA, 3, 8
 Apollo flight mode, 48, 67, 68 ill., 69
 Little Joe II/LM test, 164
 LM landing gear tests, 176
 location of manned space flight center, 19, 53
 lunar landing trainer, 164, 314, 323, 325 ill.
 material studies, 94, 172
 manned lunar program feasibility, 12, 26, 67
 parachute studies, 94
 reentry heating studies, 37, 94
 space station studies, 9, 10, 67
 WASP test (liquid-hydrogen behavior), 193
- Lanning, J. H., 39
 Lanzkron, Rolf W., 183, 196, 252, 489
 Large Launch Vehicle Planning Group. *See* Golovin Committee
 Larson, Howard, 489
 Larson, Raymond F., 489
 Larson, Robert L., 489
 Laughlin, C. Patrick, 17
 Launch Complex 34, 191, 209, 267, 270 ill.
 AS-204 activities, 213-19, 241
 Launch Complex 37, 241
 Launch Complex 39, 233 ill., 275, 289
 true location, 247
 Launch escape system, 27, 28, 29, 90, 93 ill., 94, 133, 134 ill., 135, 268
 abort tower, 27, 94, 133, 134 ill., 142 ill., 171
 Little Joe II tests, 93 ill., 141-42, 183
 rocket motor, 90
 Launch Operations Center, NASA (*see also* Kennedy Space Center, NASA), 51, 104, 118, 119
 Launch pads, Saturn, 25, 50, 92
 "all-up" decision impact, 130-31
 launch complexes. *See* Launch Complex 34, 37, 39.
 sliding wire safety device, 228, 263
 Launch vehicle concepts, multistage, 5-7, 47
 Launch vehicle development plans, 4-7, 25, 44-53-54 ill., 57, 59, 130-31
 Lawton, Richard W., 489
 Layton, P., 156
 Lee, John B., 17, 19
 Lee, William A., 159, 173, 185, 199, 230, 266, 489
 Lees, Lester, 102
 Legs (gear), lunar landing vehicle, 62, 63 ill., 68 ill., 69, 74 ill., 75, 86 ill., 92, 125, 144, 145, 145 ill.
 Apollo 9, 295, 297 ill.
 crushable honeycomb, 153, 334
 design, 151-53, 153 ill.
 footpads, 99, 151, 152, 154, 172, 173 ill., 344, 349, 350 ill.

INDEX

- frangible probes, 172, 173 ill., 344
- ladder, 151, 153 ill., 326, 346, 349, 350 ill.
- number of, 151-52
- LEM management plan, 177
- "Lemon award," Grissom, 209
- Lenticle-shaped spacecraft, 10 ill., 11
- LEO (large earth orbit), 182
- Leonov, Aleksey A., 182
- Lessing, Henry C., 489
- Levin, Kenneth, 489
- Levine, David S., 489
- Lewis Research Center, NASA, 3, 8, 56
 - Apollo flight mode, 80, 103, 106
 - barred as manned space flight location, 19
 - CM thruster studies, 92, 157
 - F-1 engine combustion instability, 122
 - hydrogen-propulsion research, 13
 - lunar landing stage (crasher), 76, 81
 - manned lunar mission feasibility, 12
- Ley, Willy, 331
- Liberty Bell 7* (MR-4), 292
- Lifting-body spacecraft, 27, 35, 37
- Lilly, William E., 58, 129
- Lina, Lindsay J., 73
- Lind, Don L., 206, 319, 324
- Lindeman, Richard E., 225
- Linder, Harry S., 489
- Ling, Donald P., 19
- Ling-Temco-Vought, Inc., 100
- Link, John, 489
- Linton, Ted, 489
- Liquid hydrogen. *See* Propellant, launch vehicle.
- Little, Arthur D., Inc., 152
- Little Joe II launch vehicle, 91-93 ill., 141, 188, 190
 - Apollo A-003, 183
 - Apollo A-004, 190
 - BP-12 flight test, 141
 - BP-22 flight test, 183
 - BP-23 flight test, 141-42
 - description, 141
 - LM test programs, 99, 109, 164
 - test program objectives, 92, 141, 190
- Lockheed Missiles & Space Co., 17, 42, 100
- Lockheed Propulsion Co., 90
- Loftin, Laurence K., Jr., 8, 10, 34
- Loftus, Joseph P., Jr., 183
- Logistics vehicle, unmanned lunar, 81-82, 362
- Long, Franklin A., 100, 219
- Long-range planning, 4, 12-13
- Lord, Douglas R., 19, 489
- Lousma, Jack R., 206, 262
- Love, Eugene S., 489
- Lovelace Foundation and Clinic, 17
- Lovell, James A., Jr. (*see also* *Apollo 8*), 116 ill., 262, 263, 282 ill., 283 ill., 318
 - Gemini VII*, 182
 - Gemini XII*, 208
- Low, George M., 28 ill., 131 ill., 308 ill., 489
 - "A to G" Apollo plan, 234, 257
 - ALSEP, 319-20
 - Apollo 6* pogo problems, 251-253
 - Apollo 7* worry list, 265
 - Apollo 8*, 275
 - Apollo 10*, 307
 - Apollo flight numbers, 231
 - Apollo flight schedule, 230-231
 - Apollo flight mode, 73, 81, 110
 - ascent engine problems, LM, 245
 - back contamination, 204
 - becomes Apollo spacecraft manager, 224
 - cabin atmosphere question, 240
 - CM, 37, 42, 133, 237, 238, 239
 - congressional testimony, 25, 110
 - extending Apollo, 364
 - first Low Committee, 20-21
 - first man on moon decision, 322
 - Goett Committee, 8, 10, 11
 - headquarters steering committee, 46
 - LM, 225, 245, 286, 302, 334
 - LRL, 204, 205
 - lunar orbit mission proposal, 256-60, 273-74
 - lunar surface operations, 319-20, 324, 326, 364
 - management council, 58, 129
 - NASA-industry conference, 15
 - 1968 worker morale problem, 256
 - OMSF organization, 121, 129
 - Panel Review Board, 168
 - parachutes versus paraglider, 96
 - planning for *Apollo 11*, 328-329, 334
 - recovery from AS-204 accident, 230, 255
 - scientist-astronaut selection, 179
 - second Low Committee, 20-21, 23, 34
 - spacesuit, 179
 - spacecraft configuration control, 230
 - spacecraft docking concerns, 287
 - spacecraft names, 331
 - space flight television, 266
 - unmanned logistics vehicle, 81
 - vehicle shipment proposal, 286
- LTA-1 (lunar test article), 175
- LTA-2, 175
- LTA-3, 175
- LTA-4, 176
- LTA-5, 175

CHARIOTS FOR APOLLO

- LTA-8, 175
- LTA-10, 175
- Luna missions (Russian program), 182, 206, 340
- "Lunar crasher" landing stage, 76, 81, 91
- Lunar exploration, unmanned, 13, 25
 - Ranger, 88, 110, 167, 181
 - Surveyor, 64, 88, 110, 123, 159, 167, 188, 205, 206
- Lunar exploration program, 12, 13, 14, 63, 82, 126, 363
- Lunar landing, manned
 - achievement, xiv, 344, 361
 - approved program, xiii, 29
 - congressional testimony for, 25
 - contractor studies, 14, 27, 28, 38
 - costs, 20, 22, 23, 25, 62
 - feasibility, 15, 27, 28
 - first, 343-44
 - first man on moon decision, 319-322
 - first mission possible, 231
 - Goett Committee, 7-11, 13
 - how-to studies, 9, 30-31, 34
 - Kennedy challenge, 29
 - launch vehicle for, 44-50, 57-59
 - Low Committee, 20-23
 - mode issue. *See* Lunar orbit rendezvous.
 - NASA ten-year plan, 12-13
 - New Projects Panel, 11
 - nine plateaus to, 201, 202
 - objectives, 110-11
 - phased program, 41
 - planning first, 314-18
 - priority, 110, 111
 - proposed as NASA's objective, xiii, 5, 8, 10, 13, 22
 - schedule, 25, 26
 - space goal, 8, 10, 11
 - steps "A through G," 234, 235
 - suggested landing sites, 125
 - 23 considerations, 203
- Lunar landing maneuvers, 62, 75, 76, 102, 315-17
- Lunar landing methods, 62, 63 ill. 75-76, 109
- Lunar landing research vehicle (LLRV), 109 ill.
- Lunar landing stage (module, vehicle), 2 ill., 14, 34, 41, 64 ill., 67, 68 ill., 69, 73-74 ill.-76, 79, 86 ill., 106, 115 ill., 145 ill.
 - "lunar crasher," 76
 - one-man, 73, 74 ill., 75
 - proposed weights, 72-73
 - two-man, 73
- Lunar landing training vehicle (LLTV), 164, 314, 322-23, 325 ill.
- Lunar landing steering committee, 46
- Lunar logistics vehicle, unmanned, 81-82, 362, 364
- Lunar mission planning, 14
- Apollo 8*, 256-60, 272-74
- Apollo 10*, 300
- Apollo 11*, 314-20
- Lunar module (LM; *earlier called* lunar excursion module, LEM), *Apollo*, xiv, xv, xvi, 68 ill., 74 ill., 81, 85, 86 ill., 87, 91, 92, 99, 102, 103, 105-108, 114, 115 ill., 127, 132, 145 ill.
 - "A to G" *Apollo* missions, 235
 - abort guidance system, 176, 311
 - ascent engine. *See* Ascent engine, LM.
 - ascent stage. *See* Ascent stage, LM.
 - attitude control thrusters, 108, 151, 154, 156-57
 - batteries. *See* Batteries, spacecraft.
 - budget problems, 177, 197
 - cabin. *See* Cabin, LM.
 - changes resulting from CM-012 fire, 225-26
 - communications system, 100, 125 ill. 158-59, 345
 - configuration, 99, 144, 145 ill. 146-47
 - contract, 105-08, 112-14, 143, 177
 - costs, 109, 114, 146, 167-68, 176-78, 190 ill., 197, 200
 - crew stations, 100, 147-48, 150 ill., 161-62
 - delivery to Cape, 176
 - descent engine. *See* Descent engine, LM.
 - descent stage. *See*, Descent stage, LM.
 - design, 98-100, 108, 109, 112, 113, 143-45 ill.-53 ill. 174, 175
 - development, 85, 146, 165-66, 256
 - docking system, 99, 108, 133, 137 ill., 145 ill., 288 ill.
 - drogue. *See* Docking, spacecraft.
 - electrical system, 108, 109, 158, 176, 286, 342
 - environmental control unit, 154, 157, 176
 - evaluation of contractor proposals, 108
 - extended lunar module (ELM), 362-64
 - fire-in-the-hole. *See* Ascent engine, LM.
 - flight test planning, 164
 - flying qualities, 287
 - frangible probes, 172, 173 ill., 344
 - fuel cells. *See* Fuel cell.
 - FTA (flight test article), 176
 - GSE (ground support equipment), 165, 176
 - guidance and navigation. *See* Guidance, control, and navigation.
 - hatches. *See* Hatch, spacecraft.
 - inflight repair. *See* Inflight spacecraft repair.
 - instrumentation, 108, 161
 - landing gear. *See* Legs (gear), lunar landing vehicle.
 - launch position, 99, 108, 132 ill., 133, 134 ill., 153 ill.
 - LM-alone flights, 205, 211, 241, 243 ill., 244

- LM-1, 198, 201, 202, 234, 241, 252
 - Apollo 5*, 242, 243 ill., 244
 - delivery to Cape, 241
 - description, 241
- LM-2, 201, 211, 244
 - broken wiring, 246
 - special test for *Apollo 11*, 334
- LM-3 (see also *Apollo 9*), 201, 253, 258, 301
 - ascent engine fuel injector, 245
 - broken wiring, 246, 256, 286
 - factor in CM lunar-orbit mission decision, 256-58
 - preflight preparations, 289
 - Spider*, 292
 - stress corrosion, 246, 256, 287
- LM-4 (see also *Apollo 10*), 201, 246, 286-87
 - Snoopy*, 302
- LM-5 (see also *Apollo 11*), 201, 245-46, 287
 - Eagle*, 331
- LM-6, 201, 246
- LM-7, 201, 246
- LM-8, 246
- LM-10, 364
- manufacturing, 147, 175-176
- mockups, 140, 161, 162 ill.
- NASA Management Review Team, 197-99
- operating environment, 144, 148
- optical tracker, 160, 173, 174, 199, 200
- pacing vehicle, 111, 158, 176, 199, 201, 256
- porch, 151, 153 ill., 296, 297 ill., 346
- propellant tankage, 144, 145 ill., 146
- propulsion system. See Propulsion system, LM.
- radar, 99, 109, 158, 159, 173, 199, 200, 298, 307
- stabilization and control system, 158
- stress corrosion (metal cracking), 237, 245-46, 286-87
- television, 159
- test program, 108, 146, 152, 154, 163, 164, 175-76
- thermal control, 109, 146-47, 151, 175
- TM (test model), 163
- tunnel, 150-51
- unmanned version, 100, 286
- visibility, 100, 102, 144, 146-47, 149, 161, 342
- weight, 99, 106, 146, 149, 151, 165, 173, 174-75, 200, 237, 247, 286
- windows, 145 ill., 146-47, 149, 150 ill., 151, 153 ill., 161, 245
- Lunar orbit insertion (LOI)
 - Apollo 8*, 278-79
 - Apollo 10*, 305-06
 - Apollo 11*, 341
- Lunar-orbit mission, first manned (see also *Apollo 8*)
 - Apollo 7* factor, 260, 271-72
 - Apollo executives meeting, 273-74
 - Cape conference, 257
 - CSM-103, 257
 - decision, 257-60, 272-74
 - designated *Apollo 8*, 260
 - Houston planning, 258-60
 - Huntsville conference, 257
 - LM-3 factor, 257
 - payload launch, weight, 273
 - "Sam's Budget Exercise," 257
 - Saturn V 503, 257, 272
 - Vienna conference, 258, 259
 - Washington conference, 258, 259
- Lunar orbital flight, manned
 - Apollo 8*, 279-82 ill.
 - Apollo 10*, 305-08 ill.-09 ill.-12
 - Apollo 11*, 341-43, 345, 347, 349, 351 ill., 352-54
- Lunar Orbiter program, 185, 188, 280, 362
- Lunar-orbiting spacecraft (see also *Apollo 8*, *Apollo 10*, and *Apollo 11*), 27, 28, 41, 110
- Lunar orbit rendezvous (Apollo lunar flight mode)
 - Ames Research Center dislike, 80
 - Apollo 10*, 309 ill., 311
 - Apollo 11*, 353
 - Apollo flight mode choice, xv, 20, 45, 48-49, 59-63 ill.-68 ill.-86 ill., 100-07, 110, 114, 117, 137, 202
 - "Charlie Frick's Road Show," 79-80
 - defense of against PSAC, 87, 100, 101-07, 110, 120
 - description, 65-67, 69
 - Dolan study group, 66-67
 - estimated cost, 20, 83, 110
 - Fleming Committee, 34, 45
 - foreseen dangers, 66, 72, 73, 80
 - Golovin Committee, 48-49, 70-72, 73, 102
 - Heaton Committee, 45, 70-71
 - Houbolt crusade, 67-73, 78, 82
 - Langley studies, 67, 69
 - Lundin Committee, 34, 45, 70
 - Marshall and Lewis losses, 81
 - Marshall switch to, 82, 83
 - mode comparison studies, 59, 77-84, 101-07
 - NASA Headquarters switch to, 80-81
 - Rosen Committee, 57-58
 - Space Task Group (later Manned Spacecraft Center) switch to, 75-79
- Lunar receiving laboratory (LRL), 126, 185, 202, 204, 332, 335 ill.
- Apollo 11*, 332-33, 354, 356 ill., 357, 359
- construction, 204-05
- cost, 205

CHARIOTS FOR APOLLO

- functions, 204, 313
- Lunar roving vehicle (LRV), 81, 362, 364
- Lunar samples. *See* Samples, lunar soil and rock.
- Lunar science program. *See* Science role in Apollo
- Lunar surface rendezvous (lunar flight mode proposal), 48, 64 ill., 65, 70
- Lunar surface study, 99, 106, 125, 152
 - Surveyor I* pictures, 206
- Lunar surface walks. *See* Walks, lunar surface
- Lunar test article (LTA), 163, 175-76
- Lundin, Bruce T., 8, 9, 19, 34, 103
- Lundin Committee, 34, 45, 70
- LUNEX, 62
- Lunik II*, 38
- Lunney, Glynn S., 190, 267, 270 ill., 303, 307
- Luskin, Harold T., 292

- McCandless, Bruce, II, 206, 341, 349
- McCafferty, Riley D., 209, 215, 489
- McCarger, Charles G., 489
- McClintock, John J., 229
- McCullough, Hugh, 197-98
- McDivitt, James A. (*see also* *Apollo 9*), 116
 - ill., 262, 263, 291 ill., 297 ill., 322, 331
 - AS-204, 224, 261
 - AS-205, 212, 261
 - Gemini IV*, 182
 - lunar-orbit mission, 262
- McDonnell Aircraft Corp., 17, 42, 43, 67, 88, 94, 100, 104-05, 108, 111, 115
- Mace, William D., 67, 489
- McGahey, Richard, 489
- McGee, Leonard A., 489
- McGinty, Earl E., 97
- McGolrick, Joseph E., 45
- McLaughlin, Richard I., 489
- McLeaish, John E., 327
- McMillan, Brockway, 19
- McNamara, Robert S., 48, 49
- M-1 rocket engine, launch vehicle, 47
- Madrid, Spain, 123
- Maggin, Bernard, 490
- Makarian, Don, 490
- MALLAR (manned lunar landing and return), 66-67
- Malley, George T., 219
- Mallick, Donald L., 490
- MALLIR (manned lunar landing involving rendezvous), 69
- Man-in-Space-Soonest, 62, 88
- Management devices, space program, 128
 - "all-up" flight testing, 130, 164, 176
 - Apollo executives committee, 129, 218, 273
 - Apollo Back Contamination Control Panel, 333
 - Apollo Program Development Plan, 168
 - Apollo Spacecraft Development Test Plan, 136, 163
 - Apollo Systems Specification Book, 121-22
 - Certification of Flight Worthiness, 169
 - Configuration Control Board, 168, 173, 230
 - Configuration Control Panels, 168, 172
 - Configuration Management Plan, 168
 - Crew Safety Review Board, 238, 240
 - Critical Design Review, 169, 170
 - Design Certification Review, 169
 - Design Reference Mission, 136-37
 - "five-box" organization system, 129
 - Flight Article Configuration Inspection, 169
 - Flight Readiness Review, 169
 - incentive contracting, 177
 - Interagency Committee on Back Contamination, 333-34
 - interface control documents, 98
 - LEM Management Plan, 177
 - lunar flight mode issue, xv, 77, 83
 - Lunar Roll of Honor, 218
 - Manned Space Flight Management Council, 58, 129
 - Materials Selection Review Board, 238
 - MFA, 218
 - mockup review boards, 133, 138, 139 ill.
 - NASA Management Review Team (LM), 197-99
 - Panel Review Board, 122, 123, 168
 - Preliminary Design Review, 169
 - PRIDE, 218
 - program control office, 129, 198
 - resident project office, 143
 - Senior Flammability Board, 238
 - spacecraft manager, 224, 231
 - subsystem managers, 135, 170-71, 175
 - system review meetings, 122, 143-44
 - Weight Control Board, 174
 - work packages, 198
- Maneuverable spacecraft, 8, 12, 16, 29, 116, 181
- Manned lunar flights. *See* *Apollo 8*, *Apollo 10*, and *Apollo 11*.
- Manned Lunar Landing Task Group. *See* Low Committee.
- Manned Space Flight Management Council, 58, 59, 78, 81, 84, 130, 286
 - established, 58, 129
 - reorganized, 129
- Manned Space Flight Network (MSFN). *See* Tracking and communications network, worldwide.
- Manned Spacecraft Center (MSC), NASA (*see also* Space Task Group, NASA), 55 ill., 186 ill.

- against unmanned lunar supply craft, 81
- Apollo guidance and navigation, 96, 97
- Apollo CM contract, 132
- Apollo CM responsibilities, 107
- Apollo LM responsibilities, 107, 108
- Apollo mode issue, 59, 82, 83
- Apollo Spacecraft Project (Program) Office. *See* Apollo Spacecraft Project (Program) Office.
- center for manned spaceflight projects, 56, 81
- Experiments Program Office, 202
- LOR defense against PSAC, 84, 103
- lunar surface questions, 99, 152
- Mission Control Center. *See* Mission Control Center.
- move to Houston announced, 52
- 1968 worker morale problem, 256
- opposition to Bellcomm contract, 121
- opposition to GE contract, 119-20
- Project Gemini, 118
- Project Mercury, 118
- reaction to AS-204 accident, 228
- relations with Langley, 92, 93
- search for location, 52
- selection criteria (*see also* Appendix A), 53
- Space Task Group renamed, 44
- tracking network question, 123, 124
- Manufacturing, spacecraft
 - CM, 90 ill., 133, 135, 210 ill., 226 ill., 229, 237, 238
 - LM, 145 ill., 147, 172, 175, 201, 241, 256
- Mardel, Alfred D., 122
- Mariner (space probe), 123
- Mark II Mercury spacecraft, 72, 75
- Markley, J. Thomas, 21, 108, 132, 172, 230, 490
- Marquardt Corp., The, 90, 92
 - CSM attitude control thrusters, 90, 92, 157
 - LM attitude control thrusters, 154, 156, 157
- Mars (planet), 7, 8, 38, 39, 362
- Marshall Space Flight Center, George C., NASA
 - "all-up" testing effects, 130-31
 - Apollo flight test program, 35, 36
 - banned as manned space flight location, 19
 - facilities, 51, 52
 - avored EOR, 21, 48, 51, 59, 63, 64, 66, 77-82
 - interface control documents repository, 123
 - Launch Operations Directorate, 51
 - launch vehicle development, 45-46, 78
 - LOR defense against PSAC, 84, 102, 104
 - LRV, 364
 - manufacturing assistance to MSC, 147, 237
 - Mississippi Test Facility, 52, 54 ill.
 - opposition to GE contract, 119
 - relations with Lewis, 122
 - relations with STG (MSC), 21
- Saturn launch vehicle. *See* Saturn launch vehicle.
- sought by NASA, 3
- suggested as manned space flight location, 53
- switch to LOR, 82, 83
- Martin Co. (Martin-Marietta), The
 - Apollo CM contract bid, 42-44
 - LM proposal, 100, 108
 - lunar mission feasibility studies, 17, 19, 26-28 ill.-29
- Martinez, R. S., 490
- Massachusetts Institute of Technology (MIT) Instrumentation Laboratory
 - Apollo CM G&N contract, 38-40 ill.
 - Apollo G&N system development, 41, 86, 96-98
 - LM G&N system development, 160-61
 - relations with G&N industrial contractors, 97-98
 - relations with spacecraft contractors, 96, 160-161, 163
- Materials, spacecraft
 - Beta fiber, 225, 228
 - flammability, 221-225, 239
 - guidelines on, 239
 - Materials Selection Review Board, 238-39
 - nonflammable, 222, 225, 226
 - Senior Flammability Board, 238
 - space effects on, 6
 - tests, 228, 239
- Materials Selection Review Board, 238-39
- Mathews, Charles W., 42, 78, 156, 182, 199, 256
- Matranga, Gene J., 490
- Mattingly, Thomas K., II, 206, 262
 - Apollo 8*, 275, 281, 283
 - Apollo 11* planning, 318, 323
- Mattson, Axel T., 94
- Maus, Hans H., 46, 57
- Maxwell, Arthur L., 490
- May, Ralph W., Jr., 8, 34
- Mayaguana (Bahama Islands), 50
- Mayer, John P., 120-21, 300, 315, 490
- Maynard, Owen E., 490
 - "A to G" Apollo plan, 234
 - CM, 138, 140
 - LM, 144, 145, 162, 174
 - LOR, 69
 - lunar mission feasibility, 17
 - nine plateaus to moon, 201
- Mayo, Alfred M., 46
- Mayo, Richard E., 176
- Mead, Margaret, 366
- Mead, Merrill H., 97
- Medical factors, astronaut, 261, 262, 269, 271, 277, 290, 293-95, 304-05, 339
- Melancon, Paul S., 490

CHARIOTS FOR APOLLO

- Meldrum, Cliff, 490
 Mendell, Wendell W., 490
 Mercury. *See* Project Mercury.
 Mercury-Atlas 1, 19
 Mercury-Atlas 3, 27
 Mercury-Atlas 6. *See* *Friendship 7*.
 Mercury-Atlas 7. *See* *Aurora 7*.
 Mercury-Atlas 8. *See* *Sigma 7*.
 Mercury-Atlas 9. *See* *Faith 7*.
 Mercury control center (space flight), 114
 Mercury-Redstone 1, 21
 Mercury-Redstone 3. *See* *Freedom 7*.
 Mercury spacecraft, 4, 9, 26, 30, 35, 94, 96,
 101, 106, 108, 111, 117, 118 ill.
 Mark II, 72
 modified, 35, 73, 116
 heatshield, 94
 Merrick, George B., 490
 Merritt Island, 50, 51, 53
 Merritt Island Launch Annex, 232
 Messina, Frank, 490
 Meteoroid hazard, spacecraft, 6, 27, 106, 110,
 167, 180-81
 Mettler, Ruben F., 128
 Meyer, André J., Jr., 156, 182, 364, 490
 MFA (manned flight awareness), 218
 Michael, William H., Jr., 67
 Michel, F. Curtis, 180
 Michoud (Saturn assembly facility), 51, 53,
 54 ill.
 Micrometeoroids, 167, 180-81
 Midcourse guidance. *See* Trajectory analysis,
 lunar flight.
 Middleton, Roderick O., 227, 257
 Miller, Edward S., 490
 Miller, Ford L., 490
 Miller, George P., 115 ill., 219
 Miller, J. S., 39
 Miller, John E., 490
 Miller, Lowell, 490
 Mills, C. V., 169
 Minneapolis-Honeywell Regulator Co., 90,
 158, 172
 Minuteman missile, 128, 164
 Mission Control Center
 Apollo, 52-53, 114-15, 186 ill., 267, 270
 ill., 356 ill.
 Gemini, 114, 186 ill.
 Mission planning, Apollo, 121-22, 136-37,
 189, 201, 211, 231, 234-35
 "A to G" missions, 234-35, 250, 256-57, 315
 Apollo 11, 314-18
 flight numbering confusion, 231-32
 Gemini contributions, 208
 lunar-orbital flight, 234, 256-57
 nine plateaus to moon, 201-02
 steps to lunar landing, 234, 235
 23 considerations for first manned moon
 landing, 203
 Mission rules, Apollo, 121-22, 137, 316
 Mississippi River, 51
 Mississippi Test Facility, NASA, 52, 55 ill.
 MIT. *See* Massachusetts Institute of Tech-
 nology.
 Mitchell, Edgar D., 206, 262, 302
 Mitchell, Elliott, 57
 Mobile Quarantine Facility (MQF), 333, 335
 ill., 356 ill., 357, 359
 Mockups and test vehicles, Apollo
 CM, 87, 88, 90 ill., 91, 91 ill., 93 ill., 132-
 33, 134 ill., 139 ill., 142 ill.
 Block I, 138, 139 ill.
 Block II, 140-41, 170-71
 BP-12 test, 141
 BP-13 test, 142
 BP-15 test, 142
 BP-23 test, 141, 142
 BP-1224 tests, 240
 SA-8 mission, 181
 SA-9 mission, 181
 SA-10 mission, 181
 LM, 90, 91, 140, 150 ill., 153 ill., 161, 162
 ill.
 M-1, 161
 M-5, 161-62
 TM-1, 161
 Mockup review boards, spacecraft
 CM, 133
 Block I, 138, 139 ill.
 Block II, 140-41
 LM, 162
 Mode questions and studies, Apollo flight,
 xv, 5-6, 27-31, 44, 48-49, 53, 57, 59-86, 101-
 07, 120
 Modular spacecraft, 14, 66
 Moe, W. R., 156
 "Molly Brown" (*Gemini III*), 292
 Mondale, Walter F., 222
 MORAD (manned orbital rendezvous and
 docking), 69
 Morehead Planetarium, 263
 Morris, Corrine L., xvi
 Morris, Owen G., 140, 170, 257, 490
 Morrow, Thomas F., 274
 Morse, Archibald E., Jr., 490
 Mortimer, Robert, 490
 Motorola, Inc., 159
 Mrasek, William A., 57
 Mueller, George E., 128, 131 ill., 296 ill., 490
 "A to G" Apollo plans, 234
 "all-up" testing, 130-31
 Apollo 5, 242, 244
 Apollo 6, 248, 250
 Apollo 8, 285
 Apollo 9, 289
 Apollo 10, 302
 Apollo 11 planning, 318, 326, 328-29, 334

INDEX

- Apollo experiments program, 202
- Apollo flight numbering confusion, 231
- AS-201, 193
- AS-204, 211, 218, 220-22, 228, 230, 232
- ascent engine problem, 244
- astronaut corps, 180, 206
- back contamination question, 333
- costs, 168, 230
- CSM, 133, 195, 196, 211, 238
- first man on moon decision, 319, 322
- flight program predictions, 253, 255
- flight schedule planning, 129-30, 131, 164, 168, 211, 229
- flight training, 208
- follow-on to Apollo, 188
- incentive contracting, 177
- inflight spacecraft repair, 159
- intervals between flights, 286, 365
- launch vehicle payload weight, 165
- LEO, 182
- LLTV, 323
- LM, 176, 198, 199, 244-246, 256
- LRL, 204
- lunar landing site selection, 185
- lunar orbit mission proposal, 258-59, 272-74
- lunar roving vehicle, 364
- lunar surface demonstration, 324, 326
- management council, 129
- Mission Control Center, 186
- optics versus radar, 174
- Panel Review Board, 168
- policy changes for Apollo, 128-30
- Saturn, 185, 195
- spacecraft atmosphere, 240
- spacecraft review steps, 168, 169
- spacesuit contract, 179
- special reviews, 286
- upgrading Apollo capabilities, 362, 364
- Mullaney, Robert S., 112, 115 ill., 149, 176, 490
- Muller, Donald E., 490
- Murder on Pad 34*, 219
- Muse, Thomas C., 13
- Myers, Dale D., 140, 169, 190, 225, 258, 265, 490
- Names, spacecraft. *See* Call signs, spacecraft.
- NASA-Industry Apollo Technical Conference (1961), 37, 70
- NASA-Industry Program Plans Conference (1960), 15
- National Academy of Sciences, 125, 180, 204
- National Advisory Committee for Aeronautics, xiii, 3
- National Aeronautics and Space Act of 1958, 2, 4
- National Aeronautics and Space Administration (NASA), xiii, xv, 4, 33, 53
- ad hoc committee work, xiv, xv, 33
- administrators, 3, 24, 322
- charter, 2-3
- field centers. *See* Ames, Goddard, High Speed Flight Station, Jet Propulsion Laboratory, Kennedy, Langley, Launch Operations, Lewis, Manned Spacecraft, Marshall, and Space Task Group.
- Headquarters, 7, 8, 12, 18, 24, 38, 45, 58, 77, 78, 80, 108, 128, 143
- Office of Advanced Research and Technology, 129
- Office of Launch Vehicle Programs, 48
- Office of Manned Space Flight, 56, 73, 83, 100, 102, 105, 121-23, 127, 129
- Office of Program Planning and Evaluation, 12
- Office of Space Flight Programs, 14, 35
- Office of Space Science and Applications, 129
- public affairs. *See* Public Affairs Office, NASA.
- reorganization, 129, 131
- role in Apollo program, 56, 118-23, 125-29
- Lunar Exploration Office, 362
- Lunar Landing Steering Committee, 46
- Lunar Role of Honor, 218
- Manned Space Flight Management Council, 58, 129
- MFA (manned flight awareness), 218
- peak years, 167
- reorganization, 46, 53, 56, 57, 129, 131
- Space Exploration Program Council, 20, 22, 69
- National Aeronautics and Space Council, 24
- National space vehicle program, 7
- Navajo missile, 43, 88
- Navigation (definition), space, 40
- Navy, U.S., 4, 92, 96, 111, 112
- Neal, James L., 156, 490
- New Projects Panel, 11
- New York Times*, 328
- Newell, Homer E., 125, 129, 179, 202, 329, 363
- Newhouse, C. W., 490
- Nicks, Oran W., 21, 23, 490
- Nicollelo, Henry, 490
- Nikoleyev, Andrian G., 115
- Nitrogen/oxygen space cabin atmosphere, 230, 239, 240
- Nitzberg, Gerald E., 490
- Nixon, Richard M., 284, 292, 319, 322, 347-48, 354, 356 ill.
- Nolan, James P., Jr., 17, 45
- North, Warren J., 45, 287, 490

CHARIOTS FOR APOLLO

- North American Aviation, Inc. (North American Rockwell Corp. after 22 Sept. 1967), 90 ill.
- Apollo mode issue, 79, 80, 101, 102, 103
- Apollo Spacecraft Development Test Plan, 135-36
- Barron report, 222-23
- CM contract, 42-44, 113, 132-33, 178, 228-29
- CM development team, 87-88 ill.-89
- CM test program, 89-93 ill., 113-14, 136, 142 ill., 163
- command module. *See* CM, Apollo.
- Design Reference Mission, 136-37
- facilities, 89, 133
- Hound Dog missile, 89, 133, 140
- LM contract bid, 100, 107, 108
- lunar mission feasibility studies, 17
- name change, 238
- 1966 problems, 194-96, 222-23
- personnel shakeup, 140, 224
- PRIDE, 218
- reaction to Apollo 204 Review Board report, 224-25, 232
- relations with Grumman, 163
- relations with MIT, 96
- Rocketdyne Div., *See* Rocketdyne Div.
- Saturn launch vehicle contracts, 58, 88
- Skybolt missile, 133
- SM. *See* SM (service module), Apollo.
- Space Div., 232
- Space and Information Systems Div., 87, 232
- subcontractors, 90, 237-38
- sued by astronauts' widows, 224
- Tulsa facility, 133
- Northrop Corp. (parachutes), 90, 94, 100
- Nose cone, Saturn, 27, 35
- Nova launch vehicle (proposed for Apollo)
- Apollo direct ascent flight mode, 8, 9, 45, 48, 49, 51, 61, 82, 84
- clustered F-1 engines, 25, 47, 49, 58
- description, 7, 20, 46, 47, 57, 58
- disadvantages foreseen, 8, 45, 48, 59, 62, 71, 77, 84
- facility assembly factor, 51
- funding, 25, 30, 45, 59
- NASA development plans, 7, 13, 20, 23, 30, 34, 45, 48, 57, 80
- solid-fueled engines, 45, 49, 58
- Nugent, John, 490
- O'Connell, J. J., 490
- O'Donnell, Kenneth, 106
- O'Hara, Delores B., 338
- Olson, R. L., 490
- One-way manned lunar flight, 65
- Onboard repair concept, spacecraft, 135, 140, 159, 171
- O'Malley, T. J., 490
- O'Neal, Robert L., 69
- Optical systems, CM, 97
- Optical systems, LM, 99, 173, 174, 199
- Optical tracker (rendezvous aid), 160, 174, 200
- Oquist, Hal O., 490
- Orbiting Astronomical Observatory, 111
- Orbital flight, manned earth, 31
- Apollo, 267-69, 270 ill., 271, 293-97 ill., 298-99
- Gemini, 181-82, 205, 207-08
- Mercury, 114, 118
- Russian programs, xiii, 25, 29-30, 115, 181, 182, 227
- Osbon, H. Gary, 138
- Ostrander, Don R., 20, 46, 53
- Ottinger, C. Wayne, 490
- Owens, W. L., 490
- Oxygen, liquid. *See* Propellant.
- Oxygen, spacecraft cabin, 157, 223, 230, 239-40
- AS-204 launch pad test procedures, 239
- versus oxygen-nitrogen, 222, 223, 230, 239-40
- Pacing Systems of the Apollo Program*, 187
- Pad 34. *See* Launch Complex 34.
- Pad abort tests, CM, 92, 93 ill., 183
- Page, Thornton L., 490
- Paige, Hilliard W., 223, 273
- Paine, Thomas O.
- Acting NASA Administrator, 267, 286
- Apollo 9*, 289
- Apollo 11* planning, 326, 329
- back contamination question, 333
- extending Apollo capabilities, 364
- first man on the moon decision, 322
- lunar orbit mission (proposal and decision), 258-59, 272-74
- NASA Administrator, 322
- NASA Deputy Administrator, 258
- Palaoro, Hans R., 122
- Panel Review Board, 122, 123, 168
- Parachutes, spacecraft, 9, 27, 29, 90, 94, 96 ill.
- Apollo 4*, 233
- clustered (3), ring-sail, 94
- glide-sail, 27
- Little Joe II launch test, 141
- Paraglider earth-landing system, 94, 96
- Parker, John A., 490
- Parkes, Australia, 328
- Parsons, John F., 52

- Pastore, Dominick J., 490
- Patch, crew
 Apollo 1, 231
 Apollo 10, 302
 Apollo 11, 331
- Patterson, Herbert G., 19
- Patton, R. Mark, 490
- Paup, John W., 44, 88 ill., 89, 133, 135, 140, 490
- Pearl River, 52
- Pearson, Ernest O., 19, 23
- Pegasus satellites, 167, 180-81
- Perrine, Calvin H., 122, 183, 490
- Pesman, Gerard J., 490
- Petrone, Rocco A., 50, 122, 168, 256, 490
 Apollo flights, 241, 242, 303, 334
 lunar orbit mission proposal, 257, 258, 273, 274
- Petynia, William W., 11, 19, 490
- Phillips, Samuel C., 128, 308 ill., 490
 "A to G" Apollo plan, 234
 Apollo flight scheduling, 164, 180
 Apollo flights, 234, 250, 266, 301, 302, 328, 329, 334
 Apollo Program Development Plan, 168
 AS-204 accident, 218, 229
 cabin atmosphere question, 240
 configuration control, 239
 enlarging the Apollo landing zone, 363
 extending Apollo capabilities, 364
 LM, 155, 156, 198, 199, 244, 245, 256, 287
 lunar mission symposium, 201
 lunar orbit mission proposal, 257, 259, 260, 272, 273, 274
 lunar surface demonstration, 325, 326
 lunar surface walks, 320, 324
 "Phillips report," 194, 195, 196, 222-223, 227
 "Sam's Budget Exercise," 257
 Saturn launch safety, 241
 space flight television, 266, 328, 329
 spacecraft docking concerns, 287
 spacecraft review steps, 168, 169
 spacesuit contract, 179
 vehicle shipment proposal, 286
- Phillips, William H., 45, 67, 490
- Photography, space
 Apollo 11, 329, 342, 347, 348, 350-51 ill., 352, 355, 365
 Apollo missions 6, 7, 8, 9, and 10, 248, 249 ill., 266, 270 ill., 278, 282 ill., 283 ill., 297 ill., 298, 308-09 ill., 310, 365
- Pickering, John E., 332
- Pickering, Richard F., 490
- Pickering, William H., 20, 62, 64, 65
- Piland, Joseph V., 205, 490
- Piland, Robert O., 16 ill., 93 ill., 490
 Apollo Projects Office, 21
 Apollo Spacecraft Project (Program) Office, 98
 CM contract, 37, 42
 CM design studies, 12, 14, 16, 17, 19
 Experiments Program Office, 202
 NASA-industry conference, 15
 vehicle attitude thrusters, 156-57
- Planetary flights, proposed manned, 188, 362
- Pogo abort sensor, 251
- Pogo problems, Saturn V, xvi
 Apollo 4, 250-51
 Apollo 6, 248, 250-52
 Apollo 8, 272, 275, 276, 288
 Apollo 10, 303
 Gemini-Titan II similarities, 302
 solution, 251-52, 257
- Pogue, William R., 206, 261, 318
- Polaris missile, 39, 96, 187
- Popovich, Pavel R., 115
- Portable life support system (PLSS; backpack), 178 ill.
 Apollo 9, 291 ill., 296, 297 ill., 298
 Apollo 11, 313, 321 ill., 345, 346, 349, 350-51 ill.
 cost and description, 296
 EMU. *See* Extravehicular mobility unit.
- Powers, John A., 327
- Pratt & Whitney Aircraft (div. of United Aircraft Corp.), 158
- Preliminary Design Review (definition), 169
- Presidential campaign of 1960, 22
- President's Science Advisory Committee (PSAC)
 Apollo 8 decision, 274
 Block I CM reliability, 170
 desires for Apollo, 362-63
 opposition to LOR mode, 84, 86, 100-08
 Panel on Man-in-Space, 19-20
 Space Vehicle Panel, 100, 101, 102, 103, 105
 President's Space Task Group, 365
- Pressure-fed spacecraft engines, 76
- Pressure launch test, maximum dynamic, 141
- Preston, G. Merritt, 490
- PRIDE ("Personal Responsibility in Daily Effort"), 218
- Probe and drogue. *See* Docking, spacecraft.
- Procter and Gamble, 196
- Production, spacecraft. *See* Manufacturing, spacecraft.
- Project Apollo. *See* Apollo program.
- "Project Christmas Present," 136, 163
- Project Gemini, xiv, 73, 114-15, 118, 129, 188, 189, 206
 contributions to Apollo, 182-83, 205, 208
 costs, 127
 dual flight, 182, 205
 influence on Apollo mission planning, 205-06

CHARIOTS FOR APOLLO

- LEO (large earth orbit), 182
- manned flights, 167, 181, 182, 205, 207, 208
- objectives, 115, 182, 183
- rivalry with Apollo, 73, 74 ill., 75, 182-83
- surplus GSE, 199
- technical problems, 127-28
- worker morale, 256
- world's first docking in space, 205
- world's first rendezvous in space, 167, 182
- Project Horizon, 62
- Project management concept, 25, 33
- Project Mercury, xiii, xiv, 3, 6, 8, 11, 15, 37, 56, 62, 88, 91, 94, 100, 101, 111, 115, 135, 180
 - approved program, 1
 - banner year, 114
 - conclusion, 128
 - difficulties, 21-24
 - follow-on to, 7, 13-15, 25-26, 66
 - modifications of, 25, 75, 116
 - move question, 18-19
 - worker morale, 19, 256
- Propellant, launch vehicle, 5, 7, 9, 13, 25, 30, 45, 47, 49, 57, 81, 99
 - cryogenic, 9, 105, 106
 - hypergolic, 9
 - liquid hydrogen, 5, 7, 13, 47, 81, 193, 194
 - nuclear, 47
 - solid, 25, 30, 45, 49, 50, 57, 58, 91, 92, 141
 - storable, 9, 105, 106
- Propellant tankage, spacecraft
 - CSM, 134 ill., 171-72, 211
 - LM, 144, 145 ill., 146
- Propst, Gary W., 215
- Propulsion modules, spacecraft, 29
- Propulsion system, lunar landing, 75-76, 99-100
- Propulsion system, LM, 108-09, 113
 - ascent engine, 113, 144, 146, 154-55, 162 ill., 200-01, 244-45
 - descent engine, 109, 113, 144, 154-56, 162 ill., 200
- Propulsion system, SM main, 90, 109, 154, 272
- Propulsion system, spacecraft, 16, 26
- Public Affairs Office, NASA, 314, 326-28
- Public Health Service, 204, 333
- Pump-fed spacecraft engines, 76
- Purser, Paul E., 19, 65, 490
- Pyle, Ray W., 169
- Quality assurance. *See* Reliability and safety, space vehicle.
- Queijo, Manuel J., 67
- Radar systems, spacecraft
 - Apollo 9*, 298
 - Apollo 10*, 301, 307, 310, 311
 - Apollo 11*, 342
 - CM, 159, 160, 173
 - LM, 99, 109, 158-60, 173-74, 187, 199-200
- Radcliffe, Lynn, 490
- Radiation, space, 6, 9-10, 20, 21, 29, 37, 102-03, 106, 110, 185
 - Gemini flights, 207
 - protection from, 16, 29, 37
- Radio Corp. of America (RCA), 42, 83
 - inflight maintenance, LM, 159
 - radar, LM, 158-159, 173, 200
 - stabilization and control system, LM, 158
- Radnofsky, Matthew I., 490
- Rafel, Norman, 45, 57
- Ragan, Ralph, 97, 490
- Ranger (space probe) program, 88, 110, 167
- Ranger VIII*, 181
- Ranger IX*, 181
- Raines, Martin L., 286, 287, 334
- Rathert, George A., 490
- Rathke, C. William, 113, 490
- Raytheon Co., 17, 97, 160, 187
- Reaction control motors, 90, 92, 94
 - ablative, 92
 - CSM, 90, 92, 94, 157, 171
 - LM, 108, 151-52, 154, 156, 157
 - test program, 92, 94
- Reaction Motors (Div. of Thiokol), 155
- Ream, Harold E., 323
- Record to 1967, manned space program, 217
- Recovery, spacecraft. *See* Landing and recovery, spacecraft.
- Recruit solid-propellant rocket motors, 141
- Rector, William F., III, 28 ill., 176, 490
 - Apollo mode issue, 79
 - LM contract, 108, 113
 - LM descent engine, 156
 - LM design, 99, 100, 108, 148, 162
 - LM guidance system, 160
- Recupito, Pasquale, 490
- Redstone Arsenal, Ala., 51, 52, 54 ill.
- Redundancy, spacecraft subsystem, 106, 135, 148
- Reece, L. D., 215, 217
- Reentry, spacecraft, 16, 25, 75, 91
 - Apollo missions, 233, 249, 271, 283, 312, 355, 358
 - guidance, 97
 - test program, 91
- Reentry control system, 92, 207-08
- Reentry corridor, earth, 97, 208
- Reentry heat protection, spacecraft, 9, 21, 26, 37, 92, 94
 - AS-201, 193
 - CM. *See* Heatshield, spacecraft ablative.
 - reaction control motors. *See* Reaction control motors.
- Rees, Eberhard F. M., 46, 58, 129, 168

- Apollo 6* pogo problem, 251
- CM manufacturing help, 237, 238
- lunar orbit mission proposal, 257, 258
- Reliability and safety, space vehicle, 121, 158
 - AS-204 reaction, 228, 230, 239
 - ascent engine, LM, 154, 155
 - cabin atmosphere, 230, 239
 - Crew Safety Review Board, 238
 - LM on launch pad, 165, 240
 - manufacturing and testing, 135, 163-64
 - redundant systems, 135, 159, 163, 193
- Rendezvous, space vehicle, 10, 13-15, 20, 23, 27, 30, 34, 44-46, 48-50, 57-59, 61-62, 67-72, 75, 80, 101, 103, 106, 110, 116
 - Apollo 7* practice, 267, 268, 270 ill.
 - Apollo 9*, 290, 297 ill., 298-99
 - Apollo 10*, 309 ill., 311
 - Apollo 11*, 352-53
 - CM-LM, 150-51
 - earth orbit. *See* Earth orbit rendezvous.
 - first (*Gemini VI-A/VII*), 167, 182
 - first international, xiv
 - Gemini IV* worries, 182
 - Gemini V* practice, 182
 - Gemini* missions, 167, 182, 205, 207, 208
 - lunar orbit. *See* Lunar orbit rendezvous
 - lunar surface. *See* Lunar surface rendezvous.
- Rendezvous sensor olympics, 174, 199, 200
- Renzetti, Nicholas A., 490
- Repair concept, spacecraft onboard, 135, 140, 159, 171
- Republic Aviation Corp., 17, 42, 100
- Research Steering Committee for Manned Space Flight. *See* Goett committee.
- Restraint harness, spacecraft, 92, 149
- Reynolds, Harry L., 174
- Rice Hotel (Houston), 132
- Rice University, 53
- Rich Building (Houston), 98
- Richard, Ludie G., 257, 259
- Richard, Louie G., 149
- Ricker, Harry H., Jr., 11
- Riehl, William, 490
- Rigsby, John, 149
- Riley, John E., 327
- Ritland, Osmond J., 62
- RL-10 hydrogen-fueled rocket engine, 155
- Roadman, Charles H., 46, 58, 129
- Rock and soil, lunar (*see also Apollo 11*), 126, 127
- Rocketdyne Div. (of North American Aviation, Inc.), 89, 92
 - CM thrusters, 92, 157
 - F-1 engine, 118, 184 ill., 251
 - Gemini* spacecraft thrusters, 92, 157
 - H-1 engine, 191
 - J-2 engine, 118, 195 ill.
 - LM ascent engine fuel injector, 244-45
 - LM descent engine, 113, 154-56
 - Saturn S-II stage, 88, 194, 195 ill.
- Rockets, spacecraft lunar landing, 62, 75
- Rogers, Henry H., 215, 217
- Roland, Alex F., xvii
- Romatowski, Ray, 46
- Roosa, Stuart A., 206, 215, 263, 292
- Rose, James T., 490
- Rose, Rodney G., 280, 315, 316, 320, 323, 490
- Rosen, Milton W., 2 ill., 8, 46, 48, 57-58, 129, 490
- Rosen committee, 57-58
- Rothrock, Addison M., 19
- Rowell, Billie D., xvi
- Rubel, John H., 46, 48, 49, 70, 177
- Rubin, Sheldon, 250
- Rudolph, Arthur, 251
- Ruppe, Harry O., 34, 45
- Ruseckas, Joseph, 490
- Russell, Harold G., 198
- Russia. *See* Union of Soviet Socialist Republics.
- Russo, Raymond R., 490
- Ryan Aeronautical Co., 159
- Ryken, John, 490
- Ryker, Norman J., Jr., 88 ill., 89, 140, 169, 490
- Saegesser, Lee D., xvii
- Safety and reliability. *See* Reliability and safety.
- St. Louis, Mo., 51
- Salina, Salvatore, 490
- Salvo rendezvous, 80
- Samples, lunar soil and rock, 126, 127, 140, 185, 202
 - Apollo 11*, 346, 348, 349, 353, 356 ill., 357, 359, 365
 - "bag of rocks" quotation, 365
- Samulon, Henry, 490
- Sasser, James H., 490
- Saturn (launch vehicle), xiv, 7-9, 13-16, 20-21, 23, 34, 35, 45, 46, 49, 51, 57-58, 62-63, 69, 79, 88, 92
 - "all-up" decision impact, 130-31
 - development contractors, 58, 119, 191
 - designations. *See* Saturn C-1 through Saturn C-5, Saturn C-8, Saturn I, Saturn IB, Saturn II, and Saturn V.
 - instrument unit, 191
 - stages. *See* Saturn launch vehicle stages.
- Saturn C-1 launch vehicle (*see also* Saturn I), 12 ill., 27, 51, 54 ill., 70
 - configuration, 47
 - first launch, 56 ill., 57

CHARIOTS FOR APOLLO

- Saturn C-1B (*see also* Saturn IB), 99, 110
 configuration, 47
 development approved, 85
- Saturn C-2, 12 ill., 21, 23, 25, 27, 64, 72
 canceled, 46
 configuration, 47
- Saturn C-3, 34, 45, 51, 72
 canceled, 47
 configuration, 47
- Saturn C-4, 45, 48–51, 58, 72
 canceled, 47
 configuration, 47
- Saturn C-5 (*see also* Saturn V), 51, 58–59
 ill., 72, 78–85, 99, 102–03, 106
 chosen for Apollo, 58
 configuration, 47
 prospective contractors, 58
 renamed, 47
- Saturn C-8, 47, 82
- Saturn-Apollo missions
 SA-6, 142 ill.
 SA-7, 142
 SA-8, 181
 SA-9, 181
 SA-10, 181
- Saturn I launch vehicle (*see also* Saturn C-1), 47, 114, 142, 181, 189
 impact of “all-up” decision, 130–31
 manned flights canceled, 130
 Pegasus flights, 181
 Saturn-Apollo (SA) flights. *See* Saturn-Apollo missions
- Saturn IB (*see also* Saturn C-1B), xvi, 47, 55 ill., 93 ill., 130, 190 ill., 192 ill., 194, 195 ill., 205, 209
 “A to G” Apollo missions, 235
 “all-up” decision impact, 130–31
 AS-204, 241
 AS-205, *See* Saturn IB missions and program assignments.
 AS-205/208, 211
 description, 47, 190, 191
 dual-launch missions, 205–06, 211
 LM test flights, 164, 241
 vehicles released, 255
- Saturn IB missions and program assignments
 201 (*see also* AS-201), 164
 202 (*see also* AS-202), 164
 203 (*see also* AS-203), 164
 204 (*see also* Apollo 5 and AS-204), 164
 205 (*see also* Apollo 7), 164, 261, 267, 270 ill.
 206, 164
 207, 164
 208, 261
- Saturn II, 9
- Saturn V, xv, xvi, 7, 47, 55 ill., 93 ill., 104, 118, 118 ill., 130, 131 ill., 184 ill., 194, 195 ill., 196 ill., 202, 229, 230, 233 ill., 241, 244, 246 ill., 247, 255
 “A to G” Apollo missions, 234–35
 Apollo missions. *See* Apollo 4, Apollo 6, and Apollo 8 through Apollo 11.
 configuration, 47
 crawler-transporter, 195, 196 ill.
 delay effects, 205
 engine, pad or launch shutdown of, 240–41
 pogo. *See* Pogo problems, Saturn V.
 stages. *See* Saturn launch vehicle stages
 S-1C, S-II, and S-IVB.
- Saturn V missions (*see also* Apollo 9, Apollo 10, and Apollo 11)
 501 (Apollo 4), 231, 232, 233 ill.
 502 (Apollo 6), 248
 503 (Apollo 8), 212, 257, 258, 261, 273, 275
- Saturn launch vehicle stages
 S-I, 47, 93 ill.
 S-IB, 47, 93 ill., 190
 S-1C, 47, 93 ill., 183, 184 ill.
 AS-501 (Apollo 4), 232–33 ill.
 AS-502 (Apollo 6), 247–48, 250
 AS-503 (Apollo 8), 276
 pogo prevention testing, 251–52
 S-II, 47, 93 ill., 185, 194–95 ill., 232, 248, 250, 252, 276
 contract award, 88
 fuel-tank model (WASP test), 193
 S-IV, 35, 47, 93 ill.
 S-IVB, 47, 49, 58, 93 ill., 105, 132 ill., 133, 150, 191, 195 ill.
 AS-201, 192
 AS-203, 193, 194
 AS-204 (Apollo 5), 242
 AS-205 (Apollo 7), 267–268, 270 ill.
 AS-501 (Apollo 4), 233–234
 AS-502 (Apollo 6), 248–50, 252
 AS-503 (Apollo 8), 276–77
 S-V, 47
- Savage, Melvin, 57
- Sawyer, Ralph S., 17
- Schedules, Apollo spacecraft, 91, 133, 136, 169
 CM, 133, 169, 171, 194, 195–96, 228–29
 LM, 146, 164, 198, 201, 227, 241, 257
- Schedules, Apollo flight, 20–23, 26, 34, 44, 63, 83, 105, 110–11, 128, 131, 187, 212
 “A to G” lunar landing plans, 234–35
 “all-up” decision impact, 130–31
 Apollo 5, 242
 Apollo 6, 248
 AS-204, 209, 211, 220–21
 impact, 229–30
 AS-205/208, 211
 AS-503, 212, 257
 Apollo pacing systems, 187

- budget effects, 168, 176
- Disher-Tischler study, 130
- intervals between flights, 286, 365
- 1968 launch, 234, 237, 244, 253, 285
- 1969 launch, 237, 285, 286
- spacecraft delivery threat, 195-96
- Scheer, Julian, 259
 - public affairs and *Apollo 11*, 326-28
 - spacecraft call signs, 302-03, 331
 - television, space flight, 266
 - symbols for *Apollo 11*, 329
- Schenk, Maurice, 156
- Scherer, Lee R., 362
- Schirra, Walter M., Jr. (*see also Apollo 7*),
 - 30, 114, 115, 115 ill., 261, 264 ill., 270 ill., 271 ill., 277
 - announced retirement, 267
 - Apollo 7* training, 262-63, 264 ill., 265
 - AS-204 hearings, 224
 - AS-205, 209, 211, 212
 - CSM-101, 261, 263, 264
 - Gemini VI*, 182
- Schmid, James E., 490
- Schmidt, Stanley F., 39
- Schmitt, Harrison H., 180, 281, 283 ill., 316, 319
- Schmitt, Joe W., 338
- Schneider, William C., 242, 248, 258, 259, 292, 490
- Schramm, Wilson B., 45, 48
- Schurmeier, Harris M., 8
- Schwarzschild, J. Martin, 19
- Schweickart, Russell L. (*see also Apollo 9*),
 - 130, 200, 291 ill., 297 ill., 490
 - AS-204, 261
 - AS-205, 212
- Science* (magazine), 131
- Science role in *Apollo*, 125-26, 179
 - Apollo 7*, 266
 - Apollo 11* postmission desires, 362-63
 - experiments, 126, 202
 - limitations, 125-27, 363
 - National Academy of Sciences, 125
 - not to interfere with *Apollo*'s prime objective, 229
 - objectives, 126, 136, 260-61
 - scientist-astronauts, 179
 - scientists' complaints, 365
 - service module bay, 140
 - Space Science Steering Committee, 125
- Scott, David R. (*see also Apollo 9*), 130, 262, 291 ill., 297 ill.
 - AS-204, 261
 - AS-205, 212
 - Gemini VIII*, 205
- Scott, Hugh M., 490
- "Scrape" (LM weight reduction), 174-75
- Seale, Leonard M., 65
- Sea of Fertility, 279, 282 ill., 341
- Sea of Tranquility, 181, 282 ill., 309 ill., 310, 317, 337
- Seamens, Robert C., Jr., 86 ill., 131 ill., 490
 - advanced program study, 20, 23, 25
 - Apollo cost estimates and funds, 25, 30, 31, 110, 127
 - Apollo flight mode, 30, 34, 59, 67-72, 78-80, 84-85, 102, 106
 - Apollo flight schedules, 25, 26, 211, 229, 230-31
 - Apollo launch vehicle question, 44-46, 48, 49, 57, 58, 85
 - Apollo program management, 24-25, 33, 34, 46, 56, 129
 - AS-204 accident, 218-21, 231
 - CM contract and development, 35, 42, 44
 - CM guidance system, 97
 - crawler-transporter, 195
 - Gemini program, 75
 - incentive contracting, 177
 - leaves NASA, 258
 - LEO, 182
 - location of manned space flight activity, 18, 52, 53
 - NASA Associate Administrator, 18, 258
 - NASA budget, 22, 23
 - NASA Deputy Administrator, 258
 - tracking network, 123
- See, Elliot M., Jr., 116, 207
 - death, 207, 217
 - Gemini IX*, 207
- Seiff, Alvin, 17
- Senior Flammability Board, 238, 239, 240
- Service module. *See* SM.
- Sevier, John R., 337, 363
- Sextant, spacecraft, 96, 97, 173, 268, 310
- Shapiro, Leonard, 50
- Shapley, Willis H., 259, 329-30
- Sharpe, Burton L., 490
- Shea, Joseph F., 86 ill., 490
 - Apollo flight mode, 59, 77-85
 - LOR defense, 100-02, 104-05, 107
 - Apollo flight planning, 164, 182, 189, 201-02
 - Apollo SM problem, 211
 - AS-204 accident, 215, 223-24
 - astronaut corps, 179
 - becomes Apollo spacecraft manager, 133
 - CM-012 problems, 211
 - CM development, 133, 135, 140, 168, 170-72
 - LM design and development, 136, 149, 176, 177, 198, 199, 201
 - LM guidance system, 159-61
 - LM propulsion system, 155-56
 - LM radar system, 173-74
 - man on the moon, 319

CHARIOTS FOR APOLLO

- management council, 58, 129
- Panel Review Board, 122-23, 168
- systems engineering activity, 56, 120-21
- Shepard, Alan B., Jr., xiii, 30, 224
- Shepard, Leonard, 490
- Sherman, Howard, 490
- Shinkle, John G., 209, 211
- Shoaf, Harry C., 74 ill., 490
- Shoemaker, Eugene M., 179
- Short Jack, 490
- Sidney, Australia, 123
- Siepert, Albert F., 20, 129, 247
- Sigma 7* (MA-8), 114, 116 ill., 266
- Silverstein, Abe, 490
 - Apollo mode issue, 66, 75, 76
 - becomes Lewis director, 56
 - CM development decision, 35, 37
 - launch vehicle development, 3, 13, 45
 - names Apollo, 15
 - space program planning, 14, 20-21, 46
- Silverstein Committee, 13
- Simpkinson, Scott H., 225, 257, 265, 490
- Simulations (simulators)
 - Apollo mission, 232-33, 249, 262-63, 275, 302, 313-14, 323, 332-34
 - astronaut water recovery, 263, 264 ill.
 - celestial navigation, 263
 - CM, 208, 209, 264 ill.
 - Gemini, 109
 - Grissom "lemon" award, 209, 215
 - launch abort, 92
 - LM, 208, 287, 291 ill., 325 ill.
 - lunar abort, 242, 244
 - lunar landing, 109, 109 ill., 110, 242, 300-01, 322, 325 ill., 326
 - lunar surface operations, 92, 321 ill., 324, 325 ill., 326
 - Mercury, 109
 - one-sixth gravity, 324, 325 ill., 364
 - pilot spacecraft control, 92
 - rendezvous, 68, 302
 - slide wire, launch pad, 263
 - vacuum chamber, 263-64, 264 ill.
- Site selection, lunar landing, 109, 125
 - Apollo zone, 363-64
 - Site Selection Board, 185, 364
 - suggested areas, 125, 363-65
- Sjoberg, Sigurd A., 140
- Skids, lunar landing vehicle, 62, 63 ill.
- Skrydloff, Leon, 490
- Skurla, George M., 490
- Skybolt missile, 133
- Skylab program, xiv, 131
- Slayton, Donald K., 30, 138, 140, 162, 174, 180, 200, 206, 209, 230, 283 ill., 308 ill., 490
 - Apollo 6* pogo problems, 251
 - Apollo 7*, 269, 271
 - Apollo 11* planning, 315, 318, 321, 323, 327-31
 - AS-204, 215-16, 224
 - crew selection policy, 318
 - lunar orbit mission proposal, 257-60, 262, 273
 - spacecraft docking concerns, 287
- Sloan, James E., 129
- Sloop, John L., 491
- SM (service module), Apollo (*see also* CM, Apollo), xiv, 41, 78, 81, 86, 87, 89, 108, 131, 132 ill., 134 ill., 139 ill., 144, 248
 - Apollo 4*, 233
 - Apollo 6*, 249
 - Apollo 7*, 267
 - Apollo 8*, 272, 276, 278, 279, 281
 - Apollo 9*, 294
 - Apollo 10*, 304, 306, 307, 312
 - Apollo 11*, 339, 341, 354, 355
 - AS-201, 192, 193
 - AS-203, 194
 - AS-204, 211
 - Block II, 193
 - contract, 132
 - docking functions, 132 ill., 133, 150
 - flight-test program, 91
 - function, 122, 193
 - science experiments bay, 140
 - weight reduction, 138
- SM-008, 248
- SM-012 (AS-204), 210 ill., 211
- SM-017 (*Apollo 4*), 211, 233
- Smedal, Harald A., 92
- Smiley, Gerald T., 274
- Smylie, Robert E., 324
- Smith, Donald W., 491
- Smith, G. Allan, 39, 491
- Smith, G. Dale, 46
- Smith, Gerald L., 491
- Smith, Joseph R., Jr., 491
- Smith, Levering, 48
- Smith, Margaret Chase, 220
- Snedekar, John, 113
- Snoopy*. *See Apollo 10*
- Soil and rock, lunar. (*see also* Appendix E), 126, 127, 136, 185, 202, 346, 348, 350-51 ill., 356 ill., 357, 359, 365
- Solar cells (electrical energy generator), 9
- Solar Particle Alert Network (SPAN), 185
- Solid propellant, rocket. *See* Propellant, rocket.
- Source Evaluation Board contract procedure, 42, 97
- Soyuz I*, 227
- Space Environment Simulation Laboratory, 263, 264 ill.
- Space Exploration Program Council, 20, 22, 69

- Space race, 5, 20, 25-26, 46, 49, 65, 104, 182-83, 189, 206, 220, 227, 340, 361
- Space science programs, unmanned, 18, 24, 39, 111
- Space Science Steering Committee, 125
- Space station. *See* Laboratory, manned space flight.
- Spacesuits. *See* Suits, space.
- Space Task Group (STG), NASA (*see also* Manned Spacecraft Center, NASA), 8, 12, 22
 - Apollo mode issue, 69, 73
 - Apollo Projects Office, 21
 - CM ((design, contract, and development), 12, 15-19, 26, 29, 35, 37, 41-42
 - formed, 4
 - launch vehicle development, 44
 - location, 18-19, 52-53
 - Marshall Space Flight Center proposal, 53
 - Mercury program, 4, 21
 - move to Houston announced, 52
 - New Projects Panel, 11
 - renamed, 44, 56
- Space Technology Committee (Stever), 4
- Space Technology Laboratories (STL; *see also* Thompson-Ramo-Wooldridge), 42, 80, 104, 112
 - LM descent engine, 155, 156
- Space walk, first, 182
- Spacecraft managers, 224-25
- Spaceport facilities, 50, 51
- Spare parts concept, spacecraft flight, 135, 140, 159, 171
- Specifications, Apollo space vehicle, 18, 121-22, 128
- Speer, Fridtjof, 122
- Sperry Rand, 88, 160, 196
- Spider* (LM-3). *See* *Apollo 9*
- Sputnik I*, xiii, 1, 25
- "Stable I" and "Stable II," CM, 263
- Stabilization and control system
 - CM, 90, 172
 - LM, 158
- Stafford, Thomas P. (*see also* *Apollo 10*), 116 ill., 267, 309 ill., 312 ill., 331, 353
 - AS-205, 209, 212, 261
 - Gemini VI*, 182
 - Gemini IX*, 207
- Stecher, Lewis J., 48
- Stehling, Kurt R., 48
- Stern, Eric, 491
- Stevens Institute of Technology, 152
- Stevenson, John D., 285
- Stever, H. Guyford, 4
- Stever committee, 4
- Stewart, Homer J., 12-13
- Steyer, Wesley L., 491
- Stinnett, Glen W., 491
- Stone, Ralph W., Jr., 67, 69
- Stonesifer, John C., 333
- Stoney, William E., Jr., 185
- Storable propellant. *See* Propellant, launch vehicle.
- Storms, Harrison A., Jr., 87, 88 ill., 89, 107, 133, 224, 230, 491
- Stoner, G. H., 274
- Strakes, CM, 133, 134 ill., 135
- Strang, Charles F., 219, 220
- Strass, H. Kurt, 11, 12, 18, 69, 491
- Strauss, Daniel T., 491
- Stress corrosion (metal cracking), spacecraft, 211, 237, 245-46, 256
- Stridde, Jack, 491
- Stuhlinger, Ernst, 5-6
- Stullken, Donald E., 271 ill.
- Suborbital manned space flight, xiii, 30-31
- Subsystem managers, Apollo spacecraft, 135, 170-71, 175, 238
- Suits, space, 92, 96, 139 ill., 153 ill., 178 ill., 313
 - Apollo 9*, 291 ill., 296, 297 ill., 298
 - Apollo Block II*, 179
 - CM mockup review, 139 ill., 178
 - extravehicular mobility unit (EMU), 178
 - ill., 291 ill., 296, 297 ill., 321 ill., 323-24, 345-46, 347 ill., 349, 350-51 ill.
 - Gemini program, 178, 179
- Sullivan, Donald B., 176
- Sullivan, Leslie J., xvii
- Surveyor (unmanned lunar soft lander), 81, 88, 110, 167, 188
 - Apollo* landing near, 363, 364
 - radar system, 159
- Surveyor I*, 205, 206
- Surveyor III*, 364
- Sutton, George P., 13
- Swigert, John L., 206, 261, 318
- SWIP (super weight improvement program), LM, 174-75
- Sword, Carl D., 97
- Syvertson, Clarence A., 26, 491
- T-38 aircraft, 262, 265
- Tanner, Trieve A., 491
- Tash, Herbert L., 333
- Taub, Willard M., 26, 490
- Taylor, Clinton L., 138, 140
- Taylor, Richard L., 490
- Teague, Olin E., 182, 183, 187, 201, 219, 223
- Telecommunications. *See* Tracking and communications network, worldwide.
- Television (receivers and transmitters), 76, 116, 123
 - Apollo 7*, 266, 269, 270 ill.
 - Apollo 8*, 276, 278, 281, 283
 - Apollo 9*, 295
 - Apollo 10*, 303, 304, 308 ill.

CHARIOTS FOR APOLLO

- Apollo 11*, 328, 329, 338, 340, 341, 346, 347, 350 ill.
- AS-203, 193
- AS-204 fire, 215, 216
- first close-up view of moon, 181
- LM, 159
- WASP flight test, 193
- Telstar communications satellite, 116
- Ten-year plan, space program, 6, 12-13
- The Moon-Doggie*, 131
- Thermal vacuum test, spacecraft, 263-64 ill.
- Thibodaux, Joseph G., Jr., 156, 244, 491
- Thiokol Chemical Corp., 90
- Thomas, Albert W., 53
- Thompson, Floyd L., 3 ill., 219, 220, 221, 491
- Thompson, William D., 491
- Thompson board. *See* Apollo 204 Review Board.
- Thompson-Ramo-Wooldridge (TRW), 200
- Thornsjo, Orelan O., 491
- Throttleable lunar-landing engine (*see also* Descent engine, LM), 9
- Thrusters, spacecraft. *See* Reaction control motors.
- Tindall, Howard W., Jr., 183, 205-06
 - Apollo lunar mission plans, 276, 283, 300-01, 315-17
 - LM flying qualities, 287
 - "Tindallgrams," 206, 316
- Tiros meteorological satellite, 25
- Tischler, Adelbert O., 57, 130, 156, 491
- Titan II missile, 59 ill., 97, 118 ill., 275, 303, 338
- Titan III missile, 57, 362
- Titterton, George F., 198
- Towl, E. Clinton, 111, 177
- Tracking and communications network, worldwide, 16, 26, 39, 90, 115, 123, 124 ill., 125, 160, 186 ill.
 - antennas. *See* Antennas, communications.
 - Apollo 8*, 274
 - Apollo 11*, 328, 345
 - Apollo program stations, 123
 - apportioned responsibilities, 185, 186
 - competition among centers, 123, 125
 - Gemini VIII*, 205
 - Gemini program stations, 185
 - Goldstone, Calif., 123, 124 ill., 206, 328
 - Mercury program stations, 123
 - Parkes, Australia, 328
 - realtime computer complex, 185
 - S-band radar system, 123, 160
 - space rendezvous role, 159-60
- Trageser, Milton B., 39, 491
- Training, astronaut, 260-61
 - Apollo 7*, 263, 264 ill., 265
 - Apollo 8*, 275
 - Apollo 9*, 291 ill., 292
 - Apollo 10*, 302
 - Apollo 11*, 313-14, 321 ill., 322-25 ill.-27
 - AS-204, 209, 210 ill., 213-14
 - celestial navigation, 263
 - philosophy, Apollo, 260-61
 - support crew innovation, 261
 - water recovery, 263, 264 ill.
 - vacuum chamber, 263, 264 ill., 323
- Trainers, Apollo
 - CM, 208, 264 ill.
 - Langley lunar landing, 109, 164, 314, 322, 325 ill., 326
 - LM, 109, 208, 291 ill., 314, 322, 325 ill.
 - LLRV, 109, 109 ill., 110
 - LLTV, 164, 322-23, 325 ill.
 - one-sixth g, 324, 325 ill., 364
- Trajectory, Saturn launch, 91, 241
- Trajectory analysis, lunar flight, 17, 26, 39, 109, 121
 - Apollo 11*, 316-18, 339
 - Apollo Trajectory Working Group, 120
 - Design Reference Mission, 136-37
 - lunar landing, 109
 - midcourse guidance, 39, 99
 - onboard operations, 39, 260
 - reentry guidance, 39
- Tranquility Base, 344, 350-51 ill., 365
- Transearth injection (TEI; insertion on trajectory toward earth), 281, 312, 354
- Transearth voyage
 - Apollo 8*, 281, 282 ill., 283
 - Apollo 10*, 312
 - Apollo 11*, 354-55
- Translunar injection (TLI), 267, 303, 339
- Translunar voyage
 - Apollo 8*, 276-78
 - Apollo 10*, 303-05
 - Apollo 11*, 339-41
- Transporter, Saturn crawler, 55 ill., 195, 196 ill., 247
- Treaties, space exploration, 218, 330
- Treinen, Terry, 491
- Treman, S. M., 169
- Trembath, Nathaniel W., 491
- Trimble, George S., Jr., 282 ill., 491
- Trimpi, Robert L., 491
- Tripp, Ralph H., 491
- Triton* (submarine), 41
- Truszynski, Gerald M., 274, 491
- Tulsa, Okla., 133
- Tunnel, spacecraft, 137, 140, 150, 151, 170 ill.
 - Apollo 9*, 293, 294
 - Apollo 10*, 304, 306, 312
 - Apollo 11*, 339, 342, 353
- Turantsky, Clem, 491
- Ulmer, Ralph E., 52
- Underwood, Richard W., 491

- Union of Soviet Socialist Republics (USSR),
xiii, 1, 26, 38, 49, 181, 182, 206, 227, 361
- United Technology Center (div. of United
Aircraft Corp.), 155
- Unmanned lunar logistics vehicle, 81, 82, 362,
364
- Unmanned space flight programs, support for
Apollo, xv, 110, 167
- Urey, Harold C., 125, 363, 365
- U.S.S. *Bennington* (Apollo 4 recovery ship),
233
- U.S.S. *Boxer* (AS-201 recovery ship), 193
- U.S.S. *Essex* (Apollo 7 recovery ship), 271
ill.
- U.S.S. *Guadalcanal* (Apollo 9 recovery ship),
299
- U.S.S. *Hornet* (AS-202 and Apollo 11 recov-
ery ship), 194, 334, 356 ill., 357, 359
- U.S.S. *Okinawa* (Apollo 6 recovery ship), 249
- U.S.S. *Princeton* (Apollo 10 recovery ship),
312
- U.S.S. *Yorktown* (Apollo 8 recovery ship),
284

- Vale, Dick, 491
- Vale, Robert E., 18, 491
- Valentine, Richard, 491
- Van Allen, James A., 37
- Van Bockel, John J., 491
- Van Dolah, Robert W., 219, 220
- Vanguard satellite, 4
- Vega (upper-stage rocket booster), 7
- Vavra, Paul H., 332
- Vehicle Assembly Building (VAB; formerly
Vertical Assembly Building), 55 ill., 131
ill., 194, 196 ill.
- Venus, proposed manned flights to, 7-8
- Visibility, space flight, 268, 305
- Voas, Robert B., 17, 179, 260
- Vogeley, Arthur W., 67, 71, 73
- von Braun, Wernher, 50, 55 ill., 80, 81, 131
ill., 164, 165, 184 ill., 211, 296 ill., 491
- "A to G" Apollo plan, 234
- "all-up" decision, 130
- Apollo flight mode, 62, 77-83, 104
- Apollo program management, 128-29
- AS-201, 191
- favored earth-orbit rendezvous, 6, 62-63,
72, 80
- launch vehicle proposals, 5-6, 13, 20
- launch vehicle test facilities, 51
- lunar orbit mission proposal, 257-59
- management council, 58, 129
- Pegasus program, 180
- relations with STG, 18, 21
- spacecraft test program, 35
- symbols for *Apollo 11*, 329
- team, 3, 7, 9, 14, 21, 51, 62, 63, 70, 76, 98

- Voris, Roy N., 491
- Voskhod spacecraft, 181
- Voskhod II*, 182
- Voss, R., 45
- Vostok program, 189
- Vostok I*, 25
- Vostok III*, 115
- Vostok IV*, 115
- Vrungos, James, 491
- Vucelik, Mike, 491

- Wade, Donald C., 491
- Walkover, Louis W., 170, 171
- Walks, lunar surface
 accomplished goal, 361
- Aldrin-Armstrong comments, 364
- Apollo 11*, 346-49, 350-51 ill.
- planning for, 313, 319-20
- post-Apollo 11 plans, 364
- priorities during *Apollo 11*, 319-20
- training for, 321 ill., 323-25 ill.-26
- Walks, space. *See* Extravehicular activities,
astronaut.
- Wallops Island, Va. 91, 193
- Ward, Douglas K., 327
- Warzecha, Ladislaus W., 26, 491
- WASP (Weightless Analysis Sounding
Probe), 193
- Waste management system, space flight, 268,
277
- Water transportation, launch vehicle, 50, 51
- Water versus land landing spacecraft, 94, 96
- Webb, James E., 28 ill., 86 ill., 131 ill., 145
ill., 180, 228, 242, 244, 246, 266
- Apollo flight mode, 46, 61, 65, 84, 85, 86
ill., 101-07
- Apollo launch vehicle, 46, 48, 49
- Apollo program approval, 25-26, 30, 33
- Apollo program development, 33
- Apollo program facilities, 52
- Apollo program management, 24-25, 56,
119-20, 127
- AS-204 accident, 218-22, 227-29, 231
- cancels crew assignments, 261
- CM contract, 38, 44, 132, 228
- CM guidance system, 41
- concludes Project Mercury, 128
- cost estimate of Apollo, 25
- leaves NASA, 267
- LEO, 182, 183
- LM contract, 107
- LOR flight mode announced, 85, 86 ill.
- LOR mode choice defended, 101-07
- lunar orbit mission proposal, 258-60, 272
- mission control center, 115
- NASA budget, 110-11, 127-28, 167
- NASA reorganization, 53, 56, 129, 130
- second NASA Administrator, 24

CHARIOTS FOR APOLLO

- Soyuz I* statement, 227
 Wedum, A. G., 332
 Weigand, Heinrich J., 48, 49
 Weight, spacecraft, xv, 16, 20-21, 23, 27, 37, 66, 69, 71-72, 77-78, 99, 106, 168, 187, 232
 CM, 138, 165, 170, 286
 LM, 99, 106, 146, 149, 151, 165, 173-75, 237, 247, 286
 Weight Control Board, 174
 Weightlessness, 102-03, 269
 Weitz, Paul J., 206
 Welch, Joseph D., 491
 Wells, Gordon, 491
 Wendt, Guenter F., 338, 491
 Wente, John S., 491
 Westinghouse Electric Corp., 159
 Weston, Kenneth C., 18
 Whitaker, Arnold B., 148, 175, 491
 White, Edward H., II, 116 ill., 261
 AS-204, 208-10 ill., 213-214
 death and burial, 216 ill., 217
 Gemini IV, 182
 widow's court action, 224
 White, George C., Jr., 219, 220, 491
 White, Stanley C., 11, 14
 White, Terry (Robert T.), 327
 White Sands, New Mex., 50, 92, 93 ill., 164
 Little Joe II flight tests, 92, 93 ill., 141, 142, 183, 190
 LM engine tests, 109, 154
 Weisner, Jerome B.
 1960 space program evaluation, 23, 24
 opposition to LOR mode choice, 84-85, 100-07
 Weisner committee and report, 23, 24
 Williams, Clifton C., Jr., 130
 AS-503, 212, 261
 death, 262
 Williams, Francis L., 48
 Williams, J. J., 169
 Williams, John J., 219, 220, 241, 308 ill.
 Williams, Laurence G., 491
 Williams, Walter C., 55 ill., 58, 93 ill., 114-15, 122, 129, 491
 Wilson, Bill, 244
 Wilson, T. A., 273
 Wilson, W. K., 53
 Wind-tunnel tests
 CM, 87, 92, 94
 earth-landing system, 94
 LM, 164
 Windows, spacecraft
 Apollo 7, 268, 289
 Apollo 8, 277, 289
 Apollo 11, 340, 342, 343, 344, 345, 346, 350-51 ill., 352-53
 CM, 171
 LM, 145 ill., 146-47, 149-50 ill.-51, 161, 245, 256
 Wingrove, Rodney C., 39, 491
 Wiring, spacecraft electrical, 225, 226 ill., 229, 238-39, 286
 Wise, Donald U., 332
 Wiseman, Donald G., 160
 Wolley, Bennie C., 333
 Wolman, William W., 48
 Wonedka, Robert P., 491
 Woodling, Carroll H., 491
 Woodward, William H., 45
 Worden, Alfred M., 206, 207, 262
 Worldwide tracking network. *See* Tracking and communications network, worldwide.
 Wren, Robert J., 334
 Wright, Howard, 491
 Wright, Monte D., xvii
 Wulfsberg, Arthur H., 491
 Wyatt, DeMarquis D., 46, 491
 Wydler, John W., 227

 X-15 aircraft, 43, 88

 York, Herbert F., 491
 Yolles, J., 45
 Yost, Harold C., 491
 Yost, Michael, 491
 Young, Earle B., 332
 Young, John W. (*see also Apollo 10*), 116 ill., 261, 309 ill., 312 ill.
 AS-205, 212, 261
 CSM-101, 263
 Gemini III, 181
 Gemini X, 207, 294
 Young, R. Wayne, 176, 197, 199

 Zaitzeff, Eugene M., 491
 Zavasky, Raymond L., 491
 Zedekar, Raymond G., 321, 322, 491

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